# ON PROCESSING LINE GRAPHS: UNDERSTANDING AGING AND THE ROLE OF SPATIAL AND VERBAL RESOURCES

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# ON PROCESSING LINE GRAPHS: UNDERSTANDING AGING AND THE ROLE OF SPATIAL AND VERBAL RESOURCES

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# SUMMARY

Visual graphs are a prevalent form of data communication and much research has been done in this domain. While there are many proposed models of graph comprehension, none directly addresses to what extent simple line graph reading tasks (trend comparison and point estimation) require spatial and verbal resources. The first goal of this study was to assess age-related differences in trend comparison and point estimation tasks presented in simple line graphs. The second goal was to investigate the extent to which verbal and spatial resources are required in trend comparison and point estimation graph tasks in younger and older adults. The present study used a dual-task paradigm to systematically investigate the relationship between attentional resources and graph reading performance for younger and older adults. Performance Operating Characteristics (POCs) were constructed, and the extent to which verbal and spatial resources are required in trend comparison and point estimation tasks were evaluated.

Both age groups performed the trend comparison and point estimation tasks well, although younger adults were significantly faster and more accurate. These data suggest that in an applied setting, line graphs can serve as a useful communication tool for identifying trends and estimating point values with a few caveats:

(1) It is unknown how older adults would perform given shorter response times. Results from this experiment suggest that a time-pressure situation may lead to performance declines for older adults.

(2) If point values must be extracted exactly, line graphs are not the ideal display for either younger or older adults.

The type of concurrent memory task (spatial or verbal) did not influence graph task performance, whereas the level of attention did influence graph performance, such that there was a "peak" in performance for both trend comparison and point estimation tasks at the 50% attention level. In this condition, participants were told that both the graph task and the memory task were equally important and to do their best on both tasks. These instructions may have provided a "motivational boost" to participants that resulted in this peak of performance during this attention level (e.g., Schmidt & Bjork, 1992).

The POCs along with the results from the repeated measures ANOVA suggest that the verbal and spatial memory tasks did not tax participants' working memory enough to influence graph performance. It is likely that the graph tasks and memory tasks were data-limited as accuracy was high on all of the tasks. The box-like patterns of the POCs illustrate pictorially the null effect of memory task on graph task performance.

Age-related differences in trend comparison and point estimation performances were identified in this sample; however, performance was high on all tasks suggesting that the participants in this study were proficient at reading graphs. The boundary conditions for these findings must continue to be investigated, as the type of concurrent memory task (spatial or verbal) did not influence graph task performance for younger or older adults. Overall, these results suggest that simple line graphs can be a viable form of communication for both younger and older adults.

# CHAPTER 1

# INTRODUCTION

Visual graphs are a common format for conveying information. A quick perusal of any newspaper, magazine, or textbook reveals this. In fact, a survey of graph usage in academic journals, magazines, and newspapers revealed 8159 graphs in 340 issues coded, and the average number of graphs per issue was 24.3 (Zacks, Levy, Tversky, & Schiano, 2002)! Moreover, Zacks et al. found that line graphs comprised over 72% of the graphs used in academic journals and nearly 50% in magazines and newspapers. Of these line graphs, more than 90% were simple two-dimensional line graphs. This study focused on simple line graphs, as they are a prevalent graph form used in various publications.

Visual graphs are intended to present data in formats that convey relationships between variables to a reader clearly and quickly (Gillan, Wickens, Hollands, & Carswell, 1998). Line graphs are particularly effective for displaying changes and trends in data over time (Kosslyn, 1994) and are used in various domains. Professionals, students, and older adults encounter line graphs in the business, school, and home environment.

The importance of relationships displayed in simple line graphs can range from money saving to life saving. For instance, simple line graphs can be used to illustrate a stock's performance throughout a trading day as well as its performance history from the past week, month, or year. This display of data can be very informative to traders who must decide when to sell and buy stocks. Additionally, line graphs can be used to monitor changes of specific health factors, such as blood pressure, heart rate, and blood sugar over time. These displays can give healthcare practitioners and individuals critical health status information to avoid health catastrophes.

### 1.1 Older Adults and Line Graphs

Graphs can provide an important tool for older adults. For example, older adults may encounter and be required to comprehend graphical displays that contain health-related information. Additionally, graphs can be relevant to older adults in the home domain, as gas and electric companies often display monthly usage trends with graphs. However, there is little research investigating the age-related differences in graph comprehension. Age-related differences in cognition and perception, including reduced spatial abilities, declines in working memory (part of the memory system used for temporarily storing and manipulating information), and declines in visual acuity (presbyopia), may influence older adults' graph comprehension performance (e.g., Craik & Salthouse, 2000; Hoyer & Verhaeghen, 2006; Park et al., 2002; Salthouse, 1992; Salthouse et al., 1990; Schieber, 2006; Zacks, Hasher, & Li, 2000). However, verbal abilities and general knowledge remain stable or increase with age (e.g., Park et al.), and could help older adults compensate for the aforementioned age-related declines.

### 1.2 Models of Graph Comprehension

The extant literature proposes several models of graph comprehension which provide some insights about the cognitive and perceptual resources required in graph comprehension. Presenting information in a graphical format requires that a reader can comprehend such a format. Some of the graph comprehension models focus singularly on perceptual processing (e.g., Cleveland & McGill, 1984; Lohse, 1993; Simkin & Hastie, 1987), whereas other theories suggest that graph comprehension involves both perceptual and cognitive processes (e.g., Carpenter & Shah, 1998; Freedman & Shah, 2002; Pinker, 1990). In general, it is agreed that visual pattern recognition occurs in the initial stage, in which readers must first perceive lines, edges, and symbols on a display. These visual elements are called the syntactic components of a graph (Kosslyn, 1989). Graph readers perceive these patterns and compare them to patterns in their graph schemas (i.e., past knowledge or experiences with graphs). This pattern recognition is followed by cognitive processes that translate and transform the perceived symbols and patterns into something meaningful to the reader.

More specifically, one model of graph comprehension has proposed that graph comprehension is an integrated and cyclical process (Carpenter & Shah, 1998; Freedman & Shah, 2002). Initial information is perceived from the graph (i.e., pattern recognition) and is driven by perceptual "chunking." Per Miller (1956), chunking is a "process of organizing or grouping the input into familiar units or chunks" (p. 93). A single pattern or chunk is then translated into a quantitative and/or qualitative interpretation via cognitive processes. Finally, the reader relates the pattern or chunk to the specific details given by the graph, such as numerical values or symbol names. This cycle repeats with the remaining portions of the graph until the entire graph has been understood by the reader. This model suggests that graph comprehension is an incremental and cyclical process, as well as an interactive top-down (knowledge driven) and bottom-up (data driven) process.

### 1.3 Factors that Influence Graph Comprehension

These models of graph comprehension suggest that there are multiple perceptual and cognitive factors that must be considered in successful graph comprehension. These factors include the specific requirements of the task, characteristics of the graph, the characteristics of the data, and the characteristics of the individual (e.g., Peebles & Cheng, 2003; Shah, Freedman, & Vekiri, 2005). Moreover, these factors have been shown to interact with each other and influence graph comprehension (e.g., graph type by task; Vessey, 1991). Because of the potential demands that these factors and their interactions can impose on readers' limited resources, these factors must be considered in graph comprehension.

**1.3.1 Task requirements.** Tasks such as reading points directly from the graph or comparing specific values shown directly in the graph are considered local tasks (Wickens & Hollands, 2000). In contrast are global tasks such as trend reading and trend comparison. Other tasks include comparing quantities that must be derived from other quantities shown in the graph (implicitly available information) or using the relationships shown on the graph to predict how one variable may change as another variable is changed. Tasks that require readers to derive information not explicitly displayed on a graph are likely to place a higher demand on a reader's resources (e.g., working memory) and to negatively affect performance.

**1.3.2 Graph characteristics.** A reader's graph comprehension success depends upon the type of graph used to display information (Kosslyn, 1989). Graph types include, but are not limited to, line graphs, bar graphs, scatter plots, and pie charts. The use of color, gridlines, and the presence of a legend are examples of graph characteristics that have been shown to influence graph readers' performances (e.g., Lohse, 1997). For example, if a legend is used, readers are likely to have to "refresh" their memory several times while trying to comprehend the graphs due to the limitations of working memory capacity, whereas directly labeling the graph can reduce the memory load on a reader (Kosslyn, 1989; Shah & Carpenter, 1995; Shah & Hoeffner, 2002).

Specific tasks are better supported in some graph types over others indicating an interaction of task demands and graph characteristics. For example, bar graphs facilitate exact point value extraction or point value comparisons between variables (Zacks & Tversky, 1999). Pie charts have been shown to support proportional data descriptions (Hollands & Spence, 1992). As line graphs directly represent slope, they are very effective in expressing changes in data over time (Zacks & Tversky). Lines graphs were proven superior in an empirical study where trend (changes over time) identification was both the most accurate and quickest for line graphs compared to vertical and horizontal bar charts (Schutz, 1961a).

These studies support Vessey's (1991) cognitive fit theory which states that a match or mismatch between the task (either symbolic or spatial) and representation (either a table or graph) influences performance. "For example, determining a trend in a set of data values requires making associations among a number of data points; that is, it requires spatial information; it is therefore a spatial task. A graph is a spatial representation since it also emphasizes spatial information" (Vessey, p. 227). Moreover, extracting a single value from many data points is a symbolic task best facilitated by a table (symbolic) representation.

**1.3.3 Data characteristics.** The complexity of the actual data presented in a graph can also influence graph reading performance. Studies have shown that the number of variables, such as the number of lines displayed in a line graph, the number of trend reversals in a line, and the number of individual data points presented influence interpretations of graphs (Carswell, Emery, & Lonon, 1993; Carpenter & Shah, 1998; Halford, Baker, McCredden, & Bain, 2005). Working memory limitations were implicated in a study that investigated the maximum number of variables that people can process simultaneously (Halford, Baker, McCredden, & Bain). Experienced graph readers were asked to interpret two-, three-, and four-way interactions represented in a bar chart. In this study task demands were manipulated by increasing the number of interactions that had to be interpreted. It was found that accuracy performance for four variables decreased significantly from three variable accuracy, and performance with five variables was at chance. This study suggested that three chunks were very difficult for readers to comprehend and four chunks were next to impossible for readers to comprehend.

In a study where the number of data points on a single line was varied and viewers were asked to describe the graph, it was suggested that single data points on a single line functioned as chunks until a certain data density was reached (Carswell, Emery, & Lonon, 1993). That is, as the number of data points increased, the resource demands increased until the working memory capacity of the viewer was overwhelmed. Once this "critical" data density was reached, the viewer described the overall or global features of the line itself and not the individual points or local features comprising the line.

**1.3.4 Person characteristics.** Characteristics of the individual reader must also be considered in graph comprehension (for a review, see Kosslyn, 1994). Working memory limitations are discussed only briefly in the literature, and age-related declines in working memory may make older adults more sensitive to task demands that tax working memory (e.g., Craik & Salthouse, 2000; Salthouse, 1992). That is, older adults' graph comprehension may be more negatively influenced when working memory demands are imposed compared to younger adults.

Moreover, an individual's knowledge of graphs as well as his/her knowledge of the specific content presented in the graph greatly influences graph comprehension (Freedman & Shah, 2002; Roth & Bowen, 2003; Shah & Carpenter, 1995; Shah & Hoeffner, 2002). These results indicate a top-down influence on graph comprehension. Although it has been demonstrated that there are many factors that can influence graph comprehension, least understood are the cognitive resources required.

### 1.4 Required Resources in Graph Comprehension

**1.4.1 Working memory.** Baddeley (1986) suggested that the working memory system was comprised of three sub-systems: the visuospatial sketchpad, the phonological loop, and the central executive. Many studies support this model (for a review see Andrade, 2001; Logie, 1995). Verbal information is maintained in the phonological loop, whereas spatial information is maintained in the visuospatial sketchpad. The "central executive" transforms and integrates the information within these stores. Working memory has a limited capacity and duration, and is therefore a known "bottleneck" in information processing (e.g., Miller, 1956). Information loss will occur if too many "chunks" are inputted into the system or if working memory must be kept active for too long (Wickens & Carswell, 1997).

The factors of task, graph, data, and person characteristics that influence graph comprehension all carry a common theme: As demands are imposed on an individual's limited resources, graph comprehension performance declines. Several studies have suggested that limited working memory plays a critical role in graph comprehension and that it can become overloaded (e.g., Carswell, Emery, & Lonon, 1993; Halford, Baker, McCredden, & Bain, 2005; Shah & Carpenter, 1995; Shah & Hoeffner, 2002). However, none of these studies systematically investigated the resource requirements of graph reading. As there are separate spatial and verbal components to working memory, how are these resources used in performing simple line graph tasks? Moreover, how do age-related changes in cognitive processes influence the resources used in simple line graph tasks?

**1.4.2 Verbal and spatial resources.** To date, no studies have directly addressed the extent to which simple line graph reading tasks (e.g., trend comparison and point estimation) require spatial and verbal resources. How does a task (e.g., point estimation or trend comparison) influence the resources required? By characterizing how both older and younger adults comprehend graphs, we can inform current research and obtain a clearer picture of the underlying processes involved in graph comprehension.

As previously described, there have been several models of graph comprehension that suggest that both spatial and verbal resources are required in reading line graphs. In a point estimation task, the target point (point of interest) must be identified or selected by the reader. Per Bryant and Somerville (1986), this task requires a “spatial move” of extrapolating an imaginary line from the function line (on which the target point is located) perpendicular to the vertical axis to extract the value of the point. Extrapolating the imaginary line from the target point to the vertical axis may require crossing over other lines in the graph, again requiring spatial resources. Finally, participants must remember the value obtained from vertical axis, tapping into a verbal resource or verbal working memory component.

In a trend comparison task, readers may have to make multiple spatial comparisons dependent on the number of displayed functions (or unique lines). As such, spatial working memory may be required to remember each line in relation to the other lines. People may hold either the location of the line or the order of the line labels in memory as they are performing the comparison, such that either spatial or verbal working memory may be used. These task analyses suggest that both verbal and spatial resources may be required in executing simple line graph tasks. Multiple resource theory (Wickens, 1984; 2002; Wickens & Hollands, 2000) provides a framework for investigating the extent to which spatial and verbal resources are required in point estimation and trend comparison graph tasks.

**1.4.3 Understanding attentional resources.** Humans have limited cognitive resources that they can apply or allocate to various processes, and each process can be overwhelmed resulting in performance declines (Navon & Gopher, 1979). Furthering this notion of limited resources, Wickens proposed a multiple resources model that described four dimensions: stages, modalities, codes, and channels (Wickens, 1984; 2002; Wickens & Hollands, 2000). This model suggests greater interference between two simultaneously performed tasks to the extent they overlap on any of these four dimensions. That is, the more resources that two tasks share, the less well the tasks will be performed. It is important to understand the resources required in graph comprehension to provide more specific and predictive models of graph comprehension.

## 1.5 Overview of the Study

The purpose of the study was to build upon the existing visual line graph research by systematically investigating the role of cognitive resources in graph comprehension. The first goal was to assess age-related differences in two graph reading (trend comparison and point estimation) tasks presented in simple line graphs. The second goal was to investigate the extent to which verbal and spatial resources are required in simple line graph tasks in younger and older adults. To that end, a dual-task paradigm was used in which participants performed the graph tasks while also performing either a verbal or spatial memory task under varying attentional conditions.

Participants were asked to complete either a trend comparison or point estimation task with full attention devoted to the task. They were then asked to complete the graph tasks and the verbal memory task simultaneously and the graph tasks and the spatial memory task simultaneously. Participants were also asked to vary their attention given to the graph and memory tasks: Full attention was to be given either to the graph tasks or to the memory tasks, or participants were asked to attend to both the graph and the memory task simultaneously devoting varying amounts of attention: 20%-80% (little attention to graph task)-(most attention to memory task); 50%-50% (both tasks of equal importance); and 80%-20% (most attention to graph task)–(little attention to memory task).

## 1.6 Performance Operating Characteristics

Individual Performance Operating Characteristics (POCs) were constructed and evaluated to provide an illustration of the extent to which verbal and spatial resources are required in trend comparison and point estimation tasks. A POC is a pictorial depiction of two tasks being performed at varying allocations of attention, and the performance of each task is plotted on each axis (Wickens, 1984; Salthouse, Rogan, & Prill, 1984; Somberg & Salthouse, 1982). The POCs provide data patterns that illustrate how the performance of the graph task changes as a function of the memory task and amount of attention.

The extent to which a POC depicts task interference (farther or closer to the POC origin) the more the two tasks overlap in resource demands (Wickens, 1984). Easier tasks will result in a POC that is farther from the origin than more difficult tasks.

> To the extent that tasks share common resources, a relatively smooth POC can be generated between them…If not, the POC will be "boxlike"…This is because if resources are disjoint between tasks, those resources freed from one task cannot be used to improve performance on the other (Wickens, p. 78).

If a graph task requires spatial resources, then adding a concurrent spatial task that is sufficiently demanding will overwhelm the available spatial resources, and the graph task performance will decline. Alternatively, if a graph task requires verbal resources, then adding a concurrent verbal task that is sufficiently demanding will result in graph task performance declines. As both spatial and alphanumeric elements must be combined in graph reading, there will likely be a differential requirement of spatial and verbal resources in point estimation and trend comparison tasks.

Figure 1 illustrates idealized potential POC patterns for the present tasks. The dashed lines creating a box-like right angle suggest that there is either no overlap of resources between the graph and memory task or that one or both of the concurrent tasks is data limited. A task is data limited when no increase in performance is observed despite the addition of more resources (Wickens, 1984). The dotted line suggests a minimal overlap of resources in that both tasks can be performed well and indicates that the graph task and the memory task are not overloading the viewer's limited resources. The solid line (or diagonal) suggests a linear function overlap of resources. That is, both tasks result in equal performance when allocating equal amounts of resources. Finally, the dashed-dotted line suggests an overlap of resources in that both tasks are not performed well and indicates that the graph task and the memory task are overloading the viewer's limited resources. The dotted, solid, and dashed lines indicate tasks that are resource limited; that is, performance changes with the addition or withdrawal of resources (Wickens).

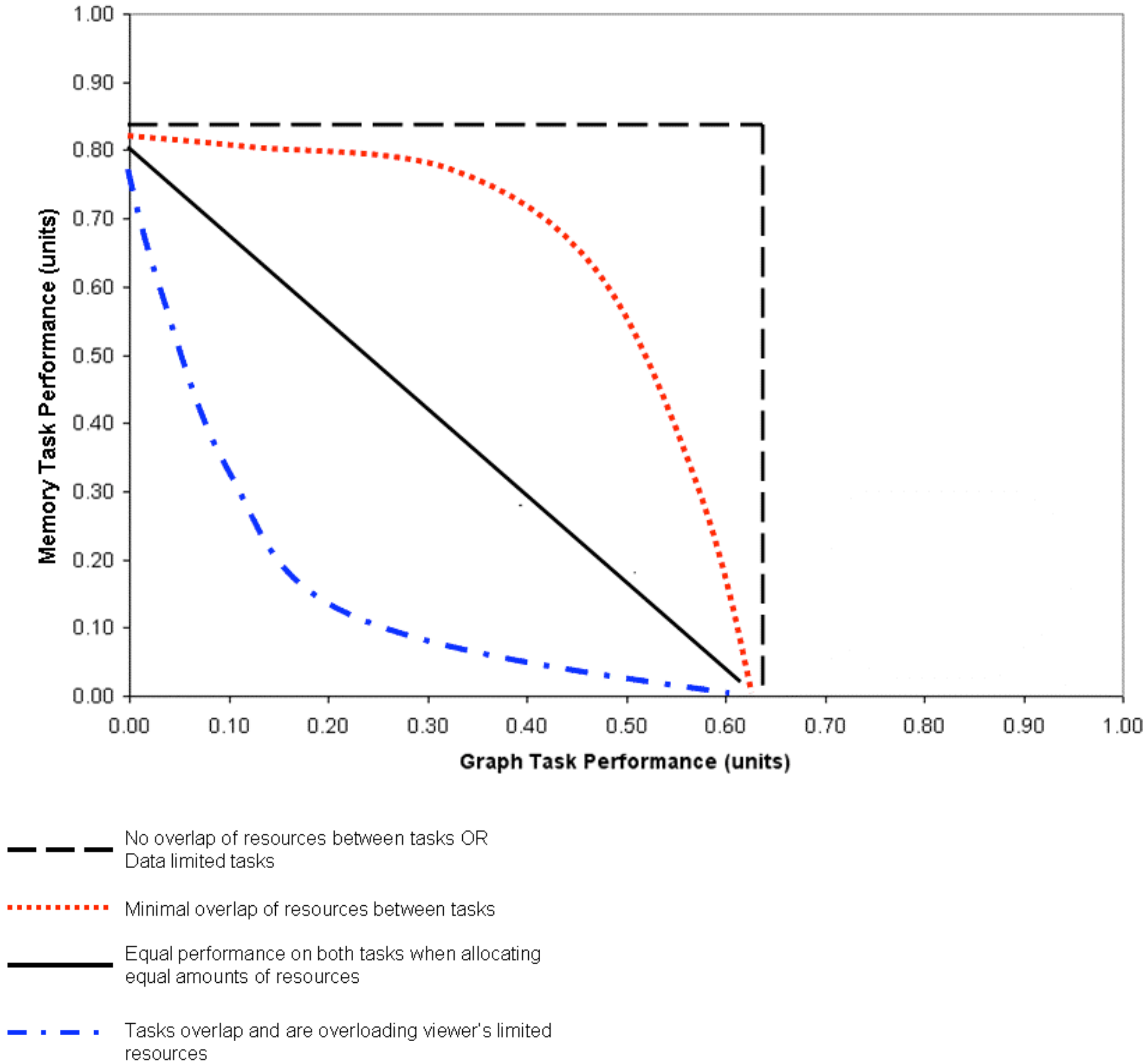


*Figure 1:* Idealized potential performance operating characteristic patterns for the experimental tasks.

## 1.7 Research Questions

The first goal of this study was to assess age-related differences in trend comparison and point estimation tasks presented in simple line graphs. It was expected that older adults would score lower on the tests of spatial ability and working memory (e.g. Bruyer & Scailquin, 1999; Craik & Salthouse, 2000; Salthouse et al., 1990), and that their performance on the memory tasks would be lower than younger adults. Because of the spatial components of line graphs described previously, it was expected that older adults' performance on both graph tasks would be lower than younger adults.

The second goal was to investigate the extent to which verbal and spatial resources are required in trend comparison and point estimation graph tasks in younger and older adults. Considering the spatial and alphanumeric components of simple line graphs, it was expected that both spatial and verbal resources are required to perform point estimation and trend comparison tasks. It was expected that each graph task requires differential verbal and spatial resources. The point estimation task was expected to require more verbal than spatial resources (e.g., Vessey, 1991), whereas the trend comparison task was expected to require more spatial than verbal resources. The POC curves would then show a greater decrement in point estimation performance as more attention was allocated to the verbal memory task than when a participant allocated more attention to the spatial memory task. The opposite pattern was expected for the trend comparison task.

Alternatively, because people can represent pictures either verbally or spatially (MacLeod, Hunt, & Mathews, 1978), the results may show that the concurrent verbal memory task interferes more than the spatial memory task for both point estimation and trend comparison tasks if participants represent a graph verbally. The opposite pattern was expected if the participants represented the graphs spatially. The POC curves were expected to show a greater decrement in point estimation performance as more attention was allocated to the verbal memory task than when participants allocate more attention to the spatial memory task given that people can represent the graph verbally. The same pattern was expected for the trend comparison task, whereas the opposite patterns would be seen if participants represented both graphs spatially.

Because of age-related declines in spatial abilities (Park et al., 2002), it was expected that older adults would use a verbal strategy in performing the point estimation and trend comparison tasks. It was expected that the pattern of the POC curves would show an incremental decline in verbal memory task performance and an incremental increase in graph task performance as more attention was devoted to the graph tasks. As older adults are less proficient in performing dual-tasks and dividing attention than younger adults, it was also hypothesized that older adults would incur a higher cost of dividing attention than younger adults (e.g., McDowd & Craik, 1988; Salthouse, Rogan, & Prill, 1984; for an overview see Rogers, 2000).

# CHAPTER 2

# METHOD

## 2.1 Participants

The younger adults were twenty-four undergraduate students from the Georgia Institute of Technology between the ages of 18 and 28 years (M=19.2, SD=1.53). Eleven of the participants were females. Twenty-nine older adults between the ages of 64 and 77 years were recruited from the Human Factors and Aging Laboratory's participant database. These were volunteers located in the Atlanta metropolitan area, who agreed to be contacted for study participation opportunities. However, six of the older adult participants' data could not be used; they were unable to successfully complete the experimental task[1]. Therefore, 23 older adults' data were used; fourteen of the older participants were females. The mean age for the older adult group was 71.3 years (SD=3.04). The older adults were a highly educated group with over 90% of the participants having some college or higher education. Younger adult participants were compensated with class credit or money or a combination of the two for their participation in this study. Older adults were compensated ten dollars per experiment hour completed.

Demographic information was collected for all participants, and each participant completed five ability tests: the Alphabet Span (Craik, 1986), the Paper Folding test (Ekstrom, French, Harman, & Derman, 1976), the Digit-Symbol Substitution test

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[1] Four of the six older adults were unable to complete all of the experimental trials within the allotted three-hour time limit. One participant did not meet the practice criterion for the graph tasks on Day 1 and for the verbal task on Day 2. The sixth participant did not follow the instructions for one of the experimental blocks and did not answer all of the graph questions.

(Wechsler, 1997), the Reverse Digit Span test (Wechsler), and the Shipley Institute of Living Scale Vocabulary test (Shipley, 1986). These ability tests provided a description of the participants. Paired samples t-tests showed statistically significant differences between age groups on every ability test. Shipley's vocabulary test was the only test in which older adults performed better than younger adults. These results are consistent with past research (Rogers, Hertzog, & Fisk, 2000). Refer to Table 1 for a summary of the ability test data.

Table 1
*Ability Test Data for Participants*

| | **Younger Adults** (N=24) | | **Older Adults** (N=23) | | |
|---|---|---|---|---|---|
| **Ability Test** | M | SD | M | SD | t-value |
| Alphabet Span (Simple)[a] | 7.65 | 1.51 | 5.72 | 1.70 | 4.11* |
| Alphabet Span (Absolute)[a] | 38.63 | 11.11 | 24.61 | 9.67 | 4.61* |
| Paper Folding Test (a)[b] | 7.32 | 2.08 | 2.41 | 1.80 | 8.43* |
| Paper Folding Test (b)[b] | 7.17 | 2.12 | 2.59 | 2.02 | 7.57* |
| Digit-Symbol Substitution[c] | 77.38 | 14.54 | 54.13 | 17.04 | 5.04* |
| Reverse Digit Span[d] | 10.21 | 2.34 | 8.70 | 2.70 | 2.05* |
| Shipley's Vocabulary[e] | 30.75 | 3.49 | 35.09 | 5.08 | -3.42* |

*Note*. *$p<.05$. [a] Working Memory (Craik, 1986); Simple span score was the level with two out of three trials correct (all the words in list in alphabetical order); Absolute span score was the total number of words recalled for trials that were recalled perfectly (absolute span, LaPointe & Engle, 1990). [b]Spatial Ability (Ekstrom, French, Harman, & Derman, 1976); Score was the total number correct from 10 items. [c]Perceptual Speed, (Weschler, 1997); Score was the total number correct of 100 items. [d]Memory Span (Weschler, 1997); Score was total correct for the 14 sets of digits presented. [e]Semantic Knowledge, (Shipley, 1986); Score was the total number correct from 40 items.

Participants' near vision and far vision was tested; participants were required to have at least 20/40 vision. One older adult participant failed the near vision criterion (obtained 20/60), but the participant's data were still used because the participant's performance was comparable to the other data.

To assess experience and familiarity with simple line graphs, participants completed a line graph questionnaire based on a questionnaire developed by Xi (2005) used to investigate how person and task characteristics influence graph comprehension. Refer to Appendix A for the line graph experience questionnaire. Participants in both groups encounter line graphs; Table 2 summarizes the frequency participants encounter line graphs (question 2 of line graph questionnaire).

Table 2
*Frequency Participants Encounter Line Graphs*

| How often do you see line graphs? | Younger Adults | Older Adults |
|---|---|---|
| Daily | 6 | 0 |
| Several times per week | 9 | 8 |
| Once per week | 6 | 4 |
| Once per month | 2 | 3 |
| Less than once per month | 1 | 5 |
| Less than once per year | 0 | 3 |
| Never | 0 | 0 |
| **TOTAL** | **24** | **23** |

### 2.2 Materials

Each participant performed the experimental task on a Dell Dimension 2350 computer with a 17-inch monitor, a standard keyboard, and a Targus external number keypad. Participants were seated approximately 20 inches from the monitor. Pink noise of approximately 55 decibels was used to reduce noise distractions during the experimental sessions. Participants were tested at separate workstations up to two per session. EPrime Version 1.15 was used to present the stimuli to the participants (Psychological Software Tools, 2003).

### 2.3 Graph Tasks

Participants answered questions presented on the computer regarding simple line graphs. Questions required participants to either identify the line that was the steepest (trend comparison task) or to identify the value of a point (point estimation task).

The graph stimuli were simple line graphs constructed using Microsoft Excel. Graphs were approximately four inches by six inches subtending a visual angle of approximately 18 degrees. Four lines were presented in every graph. The lines did not cross over each other; nor were they parallel to each other. The smallest angle of difference between the target line and the most similar distractor (or non-target) line was either 3.1 degrees (in the "difficult" condition) or 9.1 degrees (in the "easy" condition). Each line had a unique slope to prevent pop-out effect. Non-homogenous distractors (or non-targets) decrease target search efficiency and increasing target to non-target similarity also decreases search efficiency (Duncan & Humphreys, 1989).

The graphs were presented in the context of numbers only without any associated values or meanings to control for semantic or contextual influences. There were no labels or tick marks on the x-axis, as these were not necessary to perform the tasks. Legends were not used to minimize the working memory demands for the participants (e.g., Shah & Hoeffner, 2002). There was one y-axis (vertical axis) on the left side of the graph with ten labeled tick marks. The initial y-axis value was randomly determined between zero and 100 and rounded up to the next multiple of the tick mark value when necessary. The tick mark values of the y-axis varied between 1, 2, 5, and 10 to prevent participants learning a fixed scale. Two variations of each line graph stimulus were displayed in this experiment that corresponded to the task: Trend comparison graphs and point estimation graphs.

**2.3.1 Trend comparison graphs.** The four lines were black and directly labeled with the numbers "1," "2," "3," and "4" from top to bottom to minimize the demands on participants' working memory and to maximize the mapping consistency between the stimuli and answer input. Figure 2 shows an example of a graph stimulus for the trend comparison task.

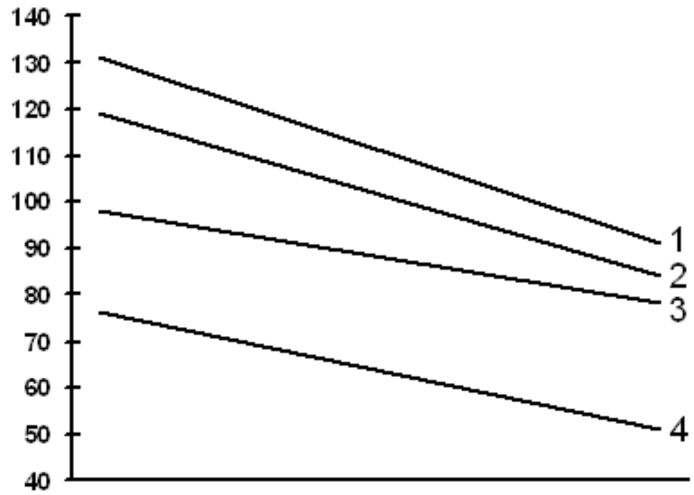


*Figure 2:* Example of a trend comparison graph stimulus.

**2.3.2 Point estimation graphs.** The graphs displayed for the point estimation task were duplicates of those used for the trend reading tasks with two modifications: First, the lines were not labeled. Second, there was one unlabeled point that appeared on one of the four lines. The point was located close to the left y-axis, in the left-middle of the graph, in the right-middle of the graph, or on the right side of the graph far from the y-axis to prevent participants from learning a fixed position of the point. Figure 3 shows an example of a graph stimulus for the point estimation task.

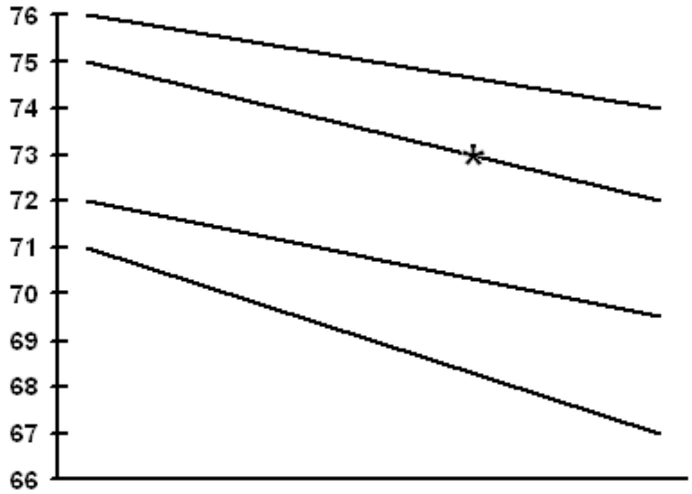


*Figure 3:* Example of a point estimation graph stimulus.

## 2.4 Memory Tasks

**2.4.1 Verbal task.** The verbal task administered was a simple letter span task of six consonants presented in a two by three array. The participant's task was to remember the letters and upon test, identify the one letter that was changed from the original array. Research has shown that this task requires verbal resources storing letters in the phonological loop (e.g., Cocchini et al., 2002; Shah & Miyake, 1996). All letters were consonants and reviewed in advance to ensure no meaningful abbreviations were included. Figure 4 shows an example of a verbal memory task.

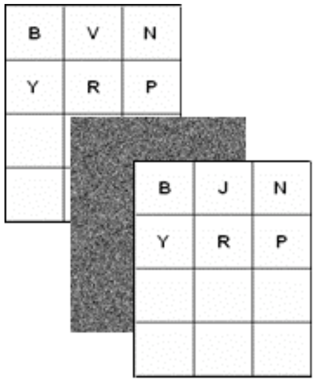


*Figure 4:* Example of a verbal memory task.

**2.4.2 Spatial task.** The spatial task was adapted from Wilson, Scott, and Power (1987). It consisted of a four by three grid with half of the squares (six) black and half white. The participant's task was to remember the grid and then to identify which one of the black squares was changed to white from the original grid. "The matrix patterns were designed to be amenable to visual rather than verbal representation...There appears to be no way in which such complex patterns could be verbally encoded and rehearsed" (Wilson, Scott, & Powers, p. 253). Figure 5 shows an example of a spatial memory task.

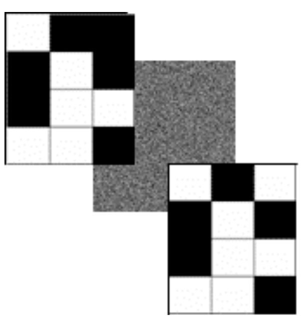

*Figure 5:* Example of a spatial memory task.

## 2.5 Experimental Procedure: Day 1

Participants were tested over three days. The first day was a group session in which all of the ability testing was completed. Younger and older adults were tested in separate groups, and there were no more than eight participants per group. Written informed consent was obtained from each participant after the nature and purpose of the study had been explained at the start of Day 1. Participants completed the Alphabet Span test (Craik, 1986), followed by a break if necessary. Then the Paper Folding test (Ekstrom, French, Harman, & Derman, 1976) was administered, followed by the Digit-Symbol Substitution test (Wechsler, 1997), the Reverse Digit Span (Wechsler) tests, and lastly the Shipley Institute of Living Scale Vocabulary test (Shipley, 1986). Participants were then scheduled for the next two sessions of the experiment, which were required to be completed on either consecutive days or with no more than one day in between testing sessions.

## 2.6 Experimental Procedure: Day 2

Participants' vision was tested at the beginning of Day 2. Next, participants completed the line graph experience questionnaire. Then they received instructions and practice on the experimental task and were given practice for the experimental task.

**2.6.1 Counterbalance assignment.** The experiment was blocked by memory task and by attention allocation. Half of the participants began with the verbal task as the memory task on Day 2 followed by the spatial task on Day 3, whereas the other half received the opposite order. These two groups were further subdivided such that half of each group performed the graph task at 100% and the memory task at 0% attention allocation, whereas the other half performed the memory task at 100% and the graph task at 0%.  The remaining levels of attention allocation (20/80, 50/50, and 80/20) were counterbalanced within each group using a Latin Square design.  Each group completed the experimental session with the same two single task conditions as at the start of the experiment.  Refer to Appendix B for more details about the counterbalance scheme.  The counterbalance scheme resulted in six conditions per group and four groups total.  A minimum of six participants had to be placed in each group to satisfy the counterbalance requirements.  Twelve participants (six younger adults and six older adults) were placed in each group, except for one group that only had five older adult participants.

**2.6.2  Practice.**  Practice trials were given according to the counterbalance group in which the participant had been assigned.  For example, a participant belonging to Group A, counterbalance 1 (refer to Appendix B), completed the experimental task in the following order for Day 2:  0/100 (0% verbal task; 100% graph task), 100/0, 20/80, 50/50, 80/20, 0/100, 100/0.  This participant received a practice block consisting of eight trials of the point estimation and trend comparison tasks (four of each) only followed by eight trials of the verbal task only.  Participants were required to get five of the eight graph practice trials correct and were given up to three blocks of practice if necessary. Participants were also required to get six of the eight verbal (or spatial) tasks correct, again receiving up to three blocks of practice if necessary. If the criterion was not met by the third practice block, the participant's data were not used.  Next, this participant received a block of dual task practice trials (four) at each of the attention allocations (five) in the order of the experiment counterbalance:  0/100 (verbal/graph), 100/0, 20/80, 50/50, and 80/20.

Throughout the practice and experimental trials, participants were instructed to work quickly and accurately. Additionally, participants received feedback at the end of each trial in the form of points earned on the task. Points were calculated based on accuracy and response time. A correct answer was necessary to receive points, but the amount of time the participant studied the graph or the verbal or spatial stimulus was also factored into the point total. A participant received more points the faster he or she studied the stimulus. The following equation describes the function used to determine points:

$$\text{Points} = (100/\text{study time in ms}) \times 1{,}000.$$

An example feedback may have stated, “You earned 25 points on the Graph Task.” During the practice trials only, the correct graph answer was given. For example, “The correct graph answer was 4.” Example feedback for the verbal and spatial tasks may have stated, “You earned 25 points on the Letter (or Grid) Task.” This feedback was given to keep the participants motivated and to encourage them to be both fast and accurate.

**2.6.3 Graph task practice.** Participants were presented with a question that appeared in the center of the monitor screen in 16-point font. A graph question, “Which line is the steepest” or “What is the value of the point?” was displayed. The participants were instructed to read and understand the question before going on as it would not be visible once the “c” key was pressed. A mask appeared for 250 ms, and then a graph was shown in the center of the upper two-thirds of the display.

When participants knew the answer to the given question, they pressed the “Spacebar,” which removed the graph from the display. Response times were recorded from the onset of the graph appearance to the depression of the "Spacebar." Then, a mask appeared for 250 ms, followed by the answer screen. Participants typed their answer (always a number) into the answer screen in the center of the display. No decimal points were used for the graph tasks. Participants could use the "Backspace" key to change their answer and the "Spacebar" to submit their answers. Upon submitting an answer, the answer screen was removed. Feedback was shown, the "c" key was pressed to continue, and the next question appeared.

**2.6.4 Verbal task practice.** Participants were presented with six letters, all consonants, in 20-point font arranged in a two by three array. The participant's task was to remember the letters; the participant pressed the "Spacebar" when he or she was ready to continue. There was a delay of one second, and the participant was presented with the same array of letters, but one of the original letters was replaced with a new letter. The participant was asked to identify the letter that was not in the original series by pressing the key on the keypad that matched the location of the new letter. Feedback was shown, the "c" key was pressed to continue, and the next letter array appeared.

**2.6.5 Spatial task practice.** The spatial task consisted of a four by three grid with half of the squares (six) black and half white. The participant pressed the "Spacebar" when he or she was ready to continue. There was a delay of one second, and the participant was presented with the same array of black and white squares, but one of the black squares was changed to white. The participant was asked to identify the square that changed from black to white from the original grid by pressing the key on the keypad that matched the location of the new letter. Feedback was shown, the "c" key was pressed to continue, and the next letter array appeared.

**2.6.6 Dual tasks.** Upon the completion of the practice single tasks, participants received dual task practice trials (four) at each of the attention allocations (five) in the order of the experiment counterbalance. The dual task practice and experimental task were identical except that the practice task gave the correct graph answer in the feedback; the experimental task did not.

Similar to the single task practice trials, participants again received feedback at the end of each trial in the form of points earned on each task. However, now the amount of attention or effort to be given to each task was factored in. A correct answer was necessary to receive points, and participants were told this. Feedback was calculated as a function of the amount of attention to be given to each task and the time taken to study each task, and participants were told to try to get as many points as possible. If a participant was instructed to give most of their attention or effort to the graph task (80% attention) and only a little effort to the memory task (20% attention), the following equations were used to calculate the feedback points:

Graph Points = (80/time spent studying the graph in ms) x 1,000

Memory Task Points = (20/time spent studying the memory task in ms) x 1,000.

A participant received more points the faster he or she studied the graph and the memory tasks. Participants were told that if they were instructed to give more attention to one task than the other, then they were to treat that task as more important and valuable than the other. Example feedback may have stated, “You earned 50 points on the Graph Task. You earned 25 points on the Grid Task.” (The spatial and verbal memory tasks were called the letter and grid tasks, respectively, for the participants.)

Participants were asked to complete either (1) the graph tasks and the verbal task simultaneously or (2) the graph tasks and the spatial task simultaneously. This was a within participants manipulation scheme counterbalanced by memory task across two days. Participants were instructed to vary their attention given to each of the tasks: 20% of their attention (or only a little of their effort) allocated to the graph task, 80% (or most of their effort) allocated to the "memory" task (noted as 20/80), 50/50, and 80/20. Single tasks (100/0 or 0/100) were performed while the other task was still occurring; participants were instructed to ignore the task that was not of interest (0% attention allocation). These single task measures were used to evaluate any performance changes that may have occurred during the experiment.

First, the verbal or spatial task was displayed. The memory task was presented until the participant pressed the "Spacebar" to continue. A mask appeared for 250 ms. Then, a graph reading question (i.e., "Which line is the steepest?" or "What is the value of the point?") was displayed. Once participants understood the graph question, they pressed "c" to continue. A mask appeared for 250 ms, and then the graph appeared. Once an answer was determined, participants pressed the "Spacebar" to move on to another 250 ms mask, and then on to the graph answer screen. Participants typed their answer on the answer screen. The "Backspace" key could be used to change answers but only before the "Spacebar" was pressed to submit an answer. Following a 250 ms mask, the verbal task or spatial task appeared asking the participant to select either which letter was not in the original series or which square had been changed from black to white. Participants entered the answer on the Targus external keypad, which had a direct mapping to the memory tasks. After participants entered their answer, feedback was given, and the sequence repeated once the participant pressed the "c" key.  Figures 6 and 7 show examples of a dual task trial.

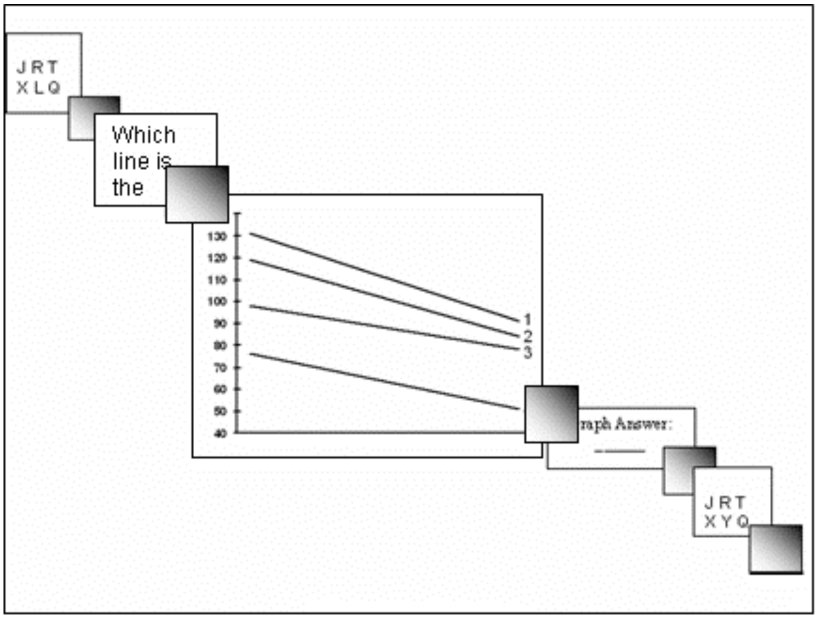


*Figure 6:* Example of a verbal and trend comparison dual task.

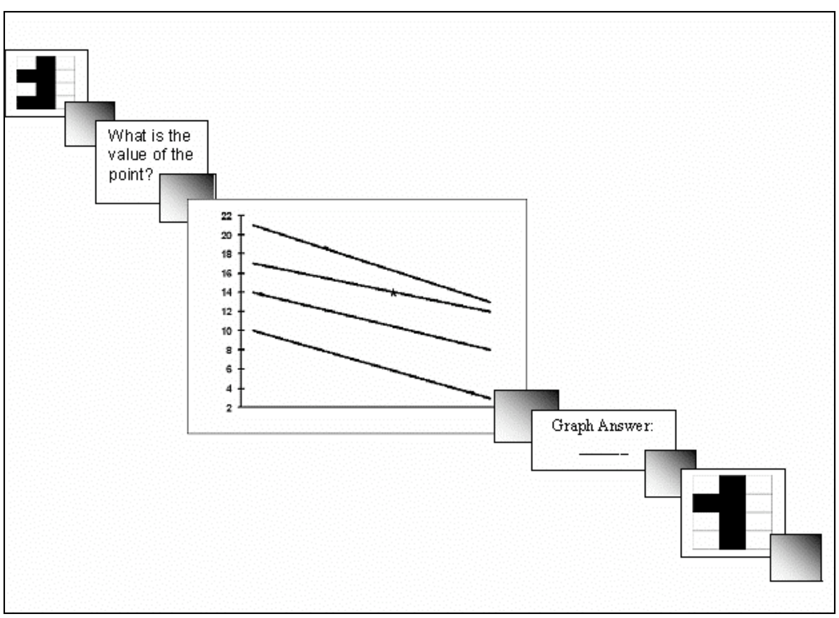


*Figure 7:* Example of a spatial and point estimation dual task.

Each graph reading task (trend comparison or point estimation) was presented eight times during each block, for a total of 16 trials per block. There was one block at each attention allocation level for a total of seven blocks (112 trials). The tasks were randomized in each block; each participant received the same random order. There were eight unique graphs presented for each block such that the point and trend estimation graphs were modified versions of each other (i.e., the point was included for the point estimation task and the line labels were include for the trend comparison task). Therefore, a total of 40 unique graphs were constructed and displayed for this experiment. The same 40 graphs were used on the third day of the experiment. The graphs presented for blocks six and seven were the same as those in blocks one and two (single task or full attention blocks). Graphs were intermixed randomly; each participant saw the same random order. See Appendix C for graph stimuli order.

Participants completed seven blocks with the verbal task and another seven blocks with the spatial tasks on two different days. There were 112 unique letter combinations displayed in the verbal letter task, not including the practice blocks. Each participant received the same order of unique letter combinations. There were 112 unique spatial memory task stimuli. The location of the black squares was random and unique; the location of the target black square was also random and unique. Each participant received the same order of spatial memory grids and verbal memory letter arrays. The activities for the second day were completed once the participant finished the seven blocks of the experimental task.

## 2.7 Experimental Procedure: Day 3

Upon returning to the lab for the third and final day, participants received the experimental instructions for the other memory task followed by practice blocks and then by the experimental blocks in the same manner as described for Day 2. Participants completed an exit interview survey at the conclusion of the experiment to understand what strategies they used during the experiment. See Appendix D for the exit interview. Participants were debriefed and compensated for their participation. See Appendix E for a detailed overview of the experimental protocol.

## 2.8 Design

The experiment was a 2 (Age: younger, older) x 2 (Graph task: trend comparison, point estimation) x 2 (Memory task: verbal, spatial) x 4 (Attention allocation: 100/0, 80/20, 50/50, 20/80) quasi-experimental split plot design. All variables were manipulated within-subjects except for age, which served as a quasi-experimental grouping variable.

# CHAPTER 3

# RESULTS

The data will be reported separately for each graph task because each used a different dependent variable. The trend comparison task dependent variables were accuracy (proportion correct) and the amount of time the graph was displayed on the monitor, or response time (RT). The point estimation task dependent variables were root mean squared error (RMSE) scores and response time (RT). Accuracy (proportion correct) and study times were also measured for the spatial and verbal memory tasks. Additionally, Performance Operating Characteristics (POCs) were constructed and comparisons made across age groups.

All tests were conducted using an alpha of .05 unless specified otherwise. Planned comparisons were conducted using paired samples t-tests. Trials that had responses out of range were trimmed from the data. For example, if the scale on the y-axis of a point estimation graph started at two and ended at 20, and a participant entered 200 as an answer, that trial was removed. Additionally, a trend comparison graph task trial was removed if an answer was given that was less than one or greater than four, as there were always four lines labeled one through four.

The goals of the study were to identify age-related differences in graph reading performance as well as changes in graph task performance as a function of concurrent memory (verbal or spatial) task performance and attention allocation. The manipulation check results will be described first followed by the results from each graph task.

## 3.1 Manipulation Check-Performance on the Memory Tasks

As a manipulation check that participants were following the attention allocation instructions and varying their attention across tasks, the study time and accuracy of the spatial and verbal memory tasks were analyzed. One-way repeated measures ANOVAs were conducted on the memory tasks at the four levels of attention (100/0, 80/20, 50/50, 20/80) for younger adults and for older adults. However, there were significant practice effects for both memory tasks between the initial and final single task (100/0) blocks such that accuracy improved and study time decreased. Therefore, the two blocks at the 100/0 level of attention were averaged because the other attention levels (20/80, 50/50, and 80/20) had only one block each.

As the memory task became less important per instructions (i.e., lower attention level), it was expected that study time should be faster and result in lower accuracy. Thus, study time at the 100% attention level would be the longest, but accuracy would be the highest. Figure 8 presents the means and standard errors of study time for each memory task by age group and attention level.

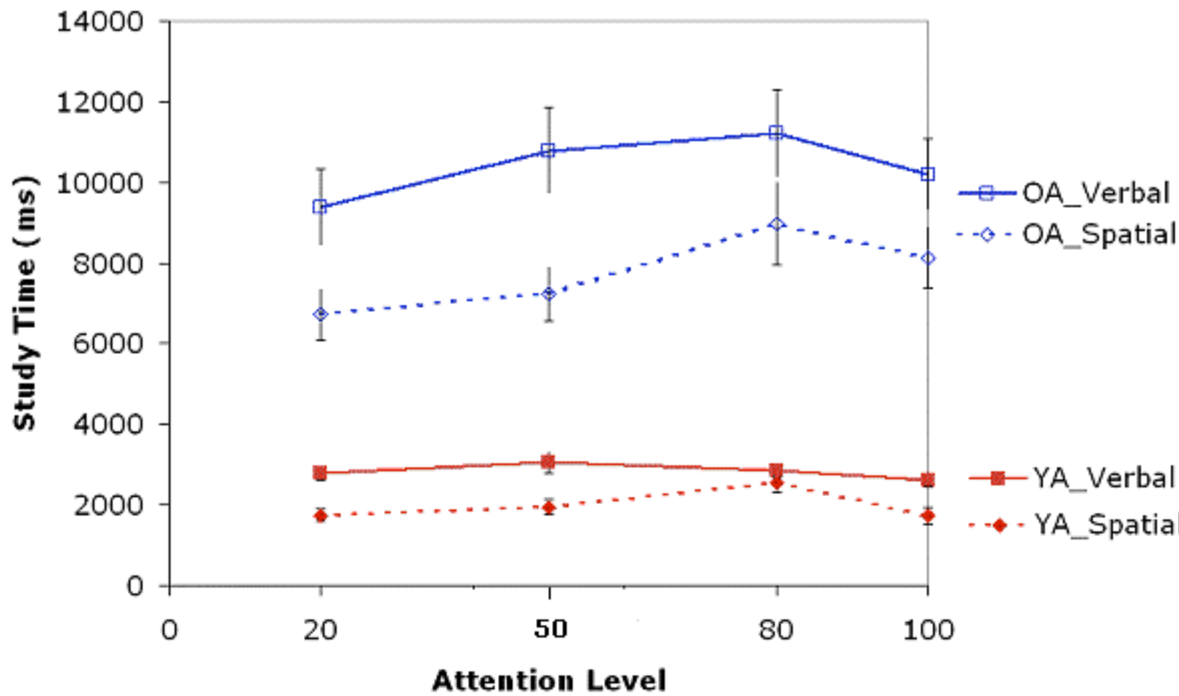


*Figure 8.* Spatial and verbal task performance by age and attention level as measured by study time. Error bars represent standard error.

The trends suggest that attention level influenced study time for both younger and older adults performing the spatial and verbal tasks. In general, participants spent the most time studying the memory stimuli in the 80% attention level and the least time studying in the 20% attention level, except for the younger adults executing the verbal task who showed little difference in study times across attention levels. See Appendix F, Table 1 for a summary of the comparisons of study time between attention levels.

The general trends in the study time data provide evidence that participants were attempting to follow the instructions to differentially allocate their attention. The accuracy data were then analyzed to investigate if the study time trends translated into accuracy differences across the attention levels. Figure 9 presents the means and standard errors of accuracy for each memory task by age group and attention level.

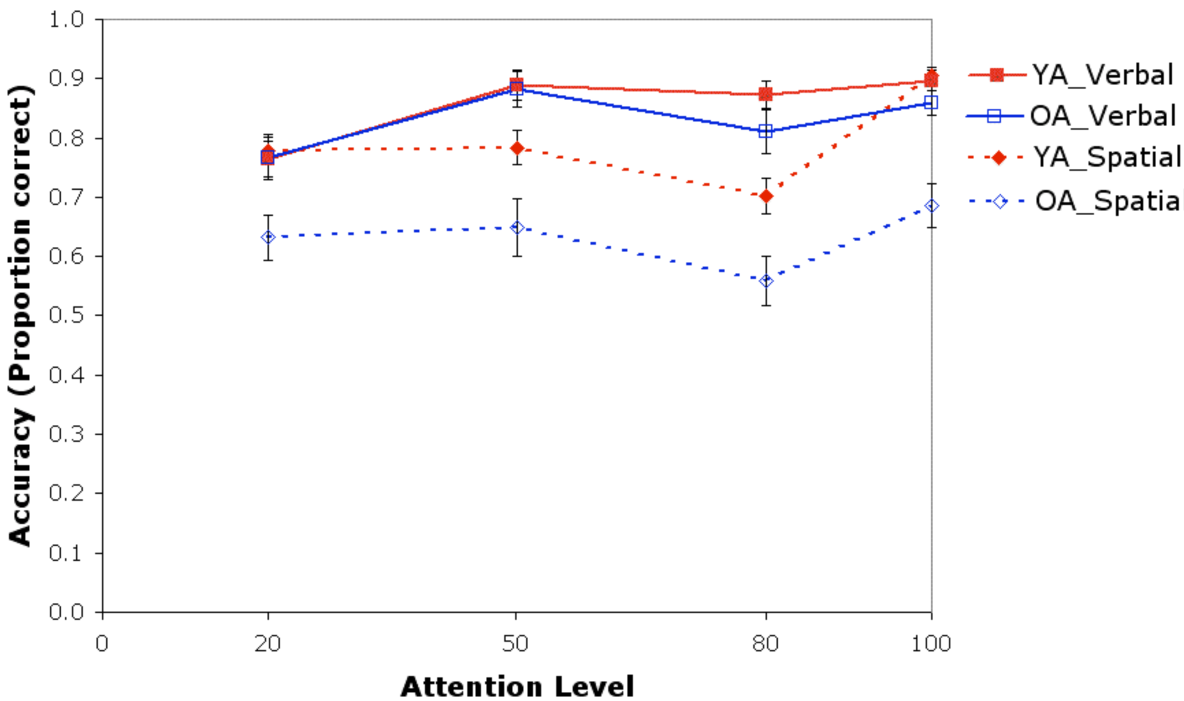


*Figure 9.* Spatial and verbal task performance by age and attention level as measured by accuracy. Error bars represent standard error.

Attention level influenced accuracy for both younger and older adults performing the spatial and verbal tasks. As expected, the mean accuracy for both the spatial and verbal memory tasks was generally highest in the 100% attention levels. However, somewhat surprisingly, mean accuracy was high for both age groups for both memory tasks in the 50% attention level. See Appendix F, Table 2 for a summary of the comparisons of accuracy between attention levels.

In summary, the overall response time and accuracy trends suggest that participants were attempting to allocate their attention as they were instructed, although the patterns across the attentional levels were somewhat mixed.

### 3.2 Trend Comparison Performance

The main focus of the study was performance on the graph tasks. Accuracy and response time (for correct trials only) were the dependent variables. The two blocks at the

100/0 level of attention were averaged because the other attention levels (20/80, 50/50, and 80/20) had only one block each. A two (Memory task: verbal, spatial) x four (Attention allocation: 100/0, 80/20, 50/50, 20/80) repeated measures ANOVA was conducted with age as the between participants variable. This analysis was intended to determine if trend comparison performance changed as a function of concurrent memory task (verbal or spatial) performance, attention allocation, and age.

**3.2.1 Accuracy.** Both age groups performed the task quite well, although the younger adults (M=.94, SD=.04) were significantly more accurate than older adults (M=.89, SD=.08), $F(1,45) = 6.03$, $p = .018$, $\eta^2 = .118$. Figure 10 provides the trend comparison accuracy data as a function of attention level and age.

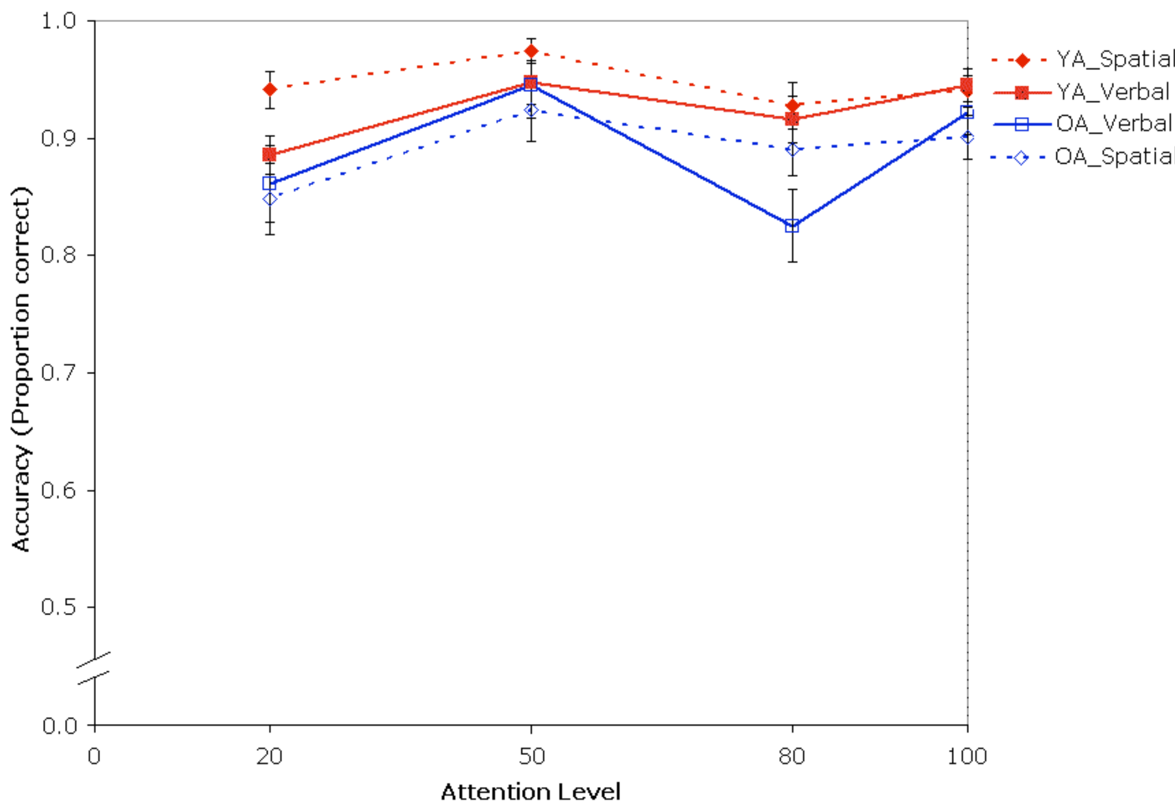


*Figure 10.* Trend comparison performance by age and attention level as measured by accuracy. Error bars represent standard error.

Accuracy on the trend comparison task was influenced by the level of attention devoted to the task as indexed by the main effect of level of attention, $F(3,43) = 10.25$, $p < .001$, $\eta^2 = .417$. This effect did not interact with age ($p = .419$). Table 3 provides the pattern of accuracy comparisons across levels of attention as determined by paired samples t-tests.

Table 3
*Paired Samples T-Test Results for Levels of Attention for Trend Comparison Task with Accuracy as the Dependent Variable*

| Comparison of Accuracy by Attention Level | t-value |
|---|---|
| 100 > 80 | 2.72* |
| 100 = 50 | -1.46$^{+}$ |
| 100 > 20 | 3.94* |
| | |
| 80 < 50 | -3.63*$^{+}$ |
| 80 = 20 | 0.45 |
| | |
| 50 > 20 | 4.73* |

*p<.05.
$^{+}$ Negative t-value indicates higher accuracy for lower attention level.

These results show that trend comparison accuracy was higher in the 100% attention level than in the 80% and 20% attention levels. Additionally, performance in the 50% attention level was higher than in the 80% and 20% attention levels.

Performance on the trend comparison task was not differentially influenced by the type of concurrent memory task, spatial or verbal, $F(1,45) = 1.18$, $p = .284$.

**3.2.2 Response time.** Overall, younger adults were faster in their response times than older adults. Moreover, level of attention differentially influenced response time for each age group, indicated by a significant interaction of level of attention and age, $F(3,43) = 3.72$, $p = .018$, $\eta^2 = .206$. See Figure 11 for an illustration of trend comparison performance by age and attention level as measured by response time. Table 4 provides the pattern of comparisons of response times across levels of attention by age group as determined by paired samples t-tests.

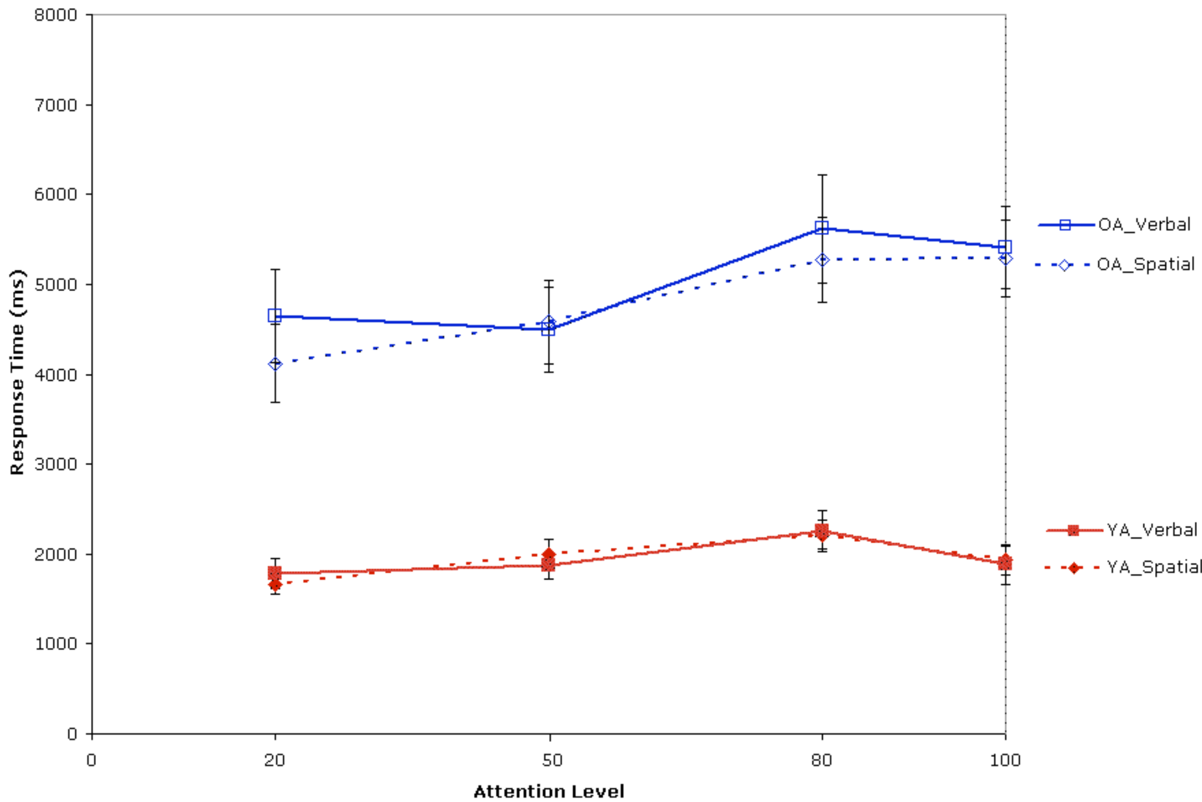


*Figure 11.* Trend comparison performance by attention level and age as measured by response time. Error bars represent standard error.

Table 4

*Paired Samples T-Test Results for Levels of Attention for Trend Comparison Task with Response Time as the Dependent Variable*

| **Younger Adults** | | **Older Adults** | |
|---|---|---|---|
| Comparison of RT by Attention Levels | t-value | Comparison of RT by Attention Levels | t-value |
| 100 < 80 | -3.30*+ | 100 = 80 | -0.64+ |
| 100 = 50 | -.31+ | 100 > 50 | 2.91* |
| 100 = 20 | 1.75 | 100 > 20 | 4.29* |
| 80 > 50 | 3.35* | 80 > 50 | 3.11* |
| 80 > 20 | 5.30* | 80 > 20 | 4.21* |
| 50 > 20 | 2.30* | 50 = 20 | 0.74 |

*p<.05.

+ Negative t-value indicates longer response time in the lower attention level.

Notice that younger adults had faster response times in the 100% attention level than in the 80% attention level, but in general, older adults had faster response times with decreasing attention levels.

Response time on the trend comparison task was not differentially influenced by performing a concurrent spatial or verbal task, $F(1,45) = .402$, $p = .529$.

**3.2.3 Performance operating characteristic.** The POC provides a descriptive illustration for trend comparison accuracy as a function of concurrent memory task accuracy. See Figure 12 for the trend comparison POC.

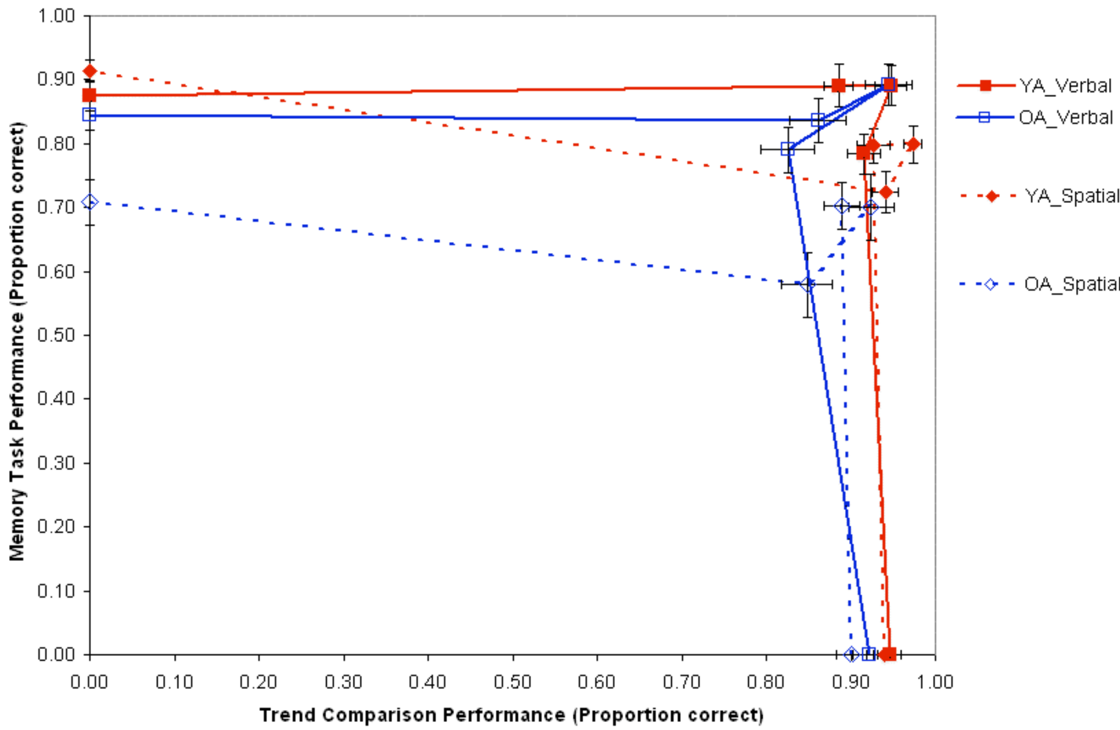


*Figure 12.* Trend comparison performance operating characteristic. Error bars represent standard error.

Both older and younger adults performed very well (above .80 accurate) in the trend comparison single task condition (refer to the x-intercepts). Verbal single task (solid lines, y-intercept) performance was also high for younger and older adults, .88 and .84, respectively. Performance on the spatial single task (dotted lines, y-intercept) was lower for older adults than for younger adults, .71 and .91, respectively.

The box-like shapes in the POC suggest that there was either no overlap of resources between the graph and memory tasks or that one or both of the concurrent tasks was data limited. The box-like patterns also suggest that the cost of dividing attention for the graph task was similar between older and younger adults. All participants performed well on the trend comparison tasks at the divided and full attention conditions, which can be seen from the nearly vertical lines between the divided attention conditions in the upper right corner and the maximum single task performance on the trend comparison task on the x-axis.

Both younger and older adults showed a decline in performance on the spatial task from the single task performance to the divided attention conditions as indexed by the dotted lines decreasing from left to right. This could suggest that the trend comparison task disrupted participants' spatial memory for the spatial task. However, performance was maintained on the trend comparison task.

To determine the cost of dividing attention on task performance, the differences between areas under the maximum performance curves and the divided attention curves on the POC were calculated using a modified version of Salthouse, Rogan, and Prill's (1984) method. Because the divided attention points on the POC did not follow a regular descending curve (points were clustered in the upper right of the POC space), the average of the divided attention values was calculated for each age group for each memory task. Next, the maximum performance area was calculated for each of the four groups by multiplying the maximum single task performance on the memory task (y-intercept value) and on the trend comparison task (x-intercept value). Then, the difference in area between the maximum performance curve and the divided attention curve was calculated to yield the cost of dividing attention. The percentage cost was computed by dividing the cost of dividing attention area by the maximum performance area and multiplying by 100. This method assumes that performance on these tasks in other attentional conditions will lie along these curves. These values are listed in Table 5 and give a quantitative description of the POC patterns.

Table 5
*Trend Comparison POC Maximum Performance and Cost of Dividing Attention*

| Memory Task | | Younger Adults | Older Adults |
|---|---|---|---|
| **Spatial** | Maximum Performance (in units$^2$) | 0.86 | 0.64 |
| | **Cost** of Dividing Attention (in units$^2$) | -0.062 | -0.026 |
| | **Percent Cost** of Dividing Attention (in units$^2$) | -7.2% | -4.1% |
| **Verbal** | Maximum Performance (in units$^2$) | 0.84 | 0.77 |
| | **Cost** of Dividing Attention (in units$^2$) | -0.027 | -0.034 |
| | **Percent Cost** of Dividing Attention (in units$^2$) | -3.2% | -4.4% |

Note: Larger the maximum performance area indicates better performance.

Younger and older adults showed similar patterns and had similar costs of dividing attention for the verbal task. Additionally, younger adults showed the highest decrement of performance with a relative cost of 7.2% during the spatial task.

**3.2.4 Trend comparison summary.** In summary, both younger adults and older adults demonstrated high performance on trend comparison task as measured by accuracy, although younger adults were more accurate than older adults. In general, accuracy was higher during higher attention levels with one exception: Accuracy was higher during the 50% attention level than in the 80% attention level.

Overall, older adults were slower to respond than younger adults. Attention level interacted with age such that younger adults had a faster response time during the 100% attention level than the 80% attention level, whereas older adults' response times were faster with decreasing levels of attention in general. Overall, participants were less accurate but faster at lower levels of attention suggesting a speed accuracy trade off.

Performing a concurrent spatial or verbal task did not differentially influence trend comparison performance as measured by either accuracy or response time, suggesting that the memory tasks did not tax participants' working memory enough to influence graph performance.

The POC patterns were similar for older and younger adults. The box-like patterns of the POCs suggest that there was either no overlap of resources between the graph and memory tasks or that one or both of the concurrent tasks was data limited. Younger adults showed the highest cost of dividing attention during the spatial task. Both age groups showed similar costs of dividing attention during the verbal task.

**3.3 Point Estimation Performance**

Accuracy (as measured by root mean squared error) and response time were used as the dependent variables for performance on the graph point estimation task. All trials were used for the response time analysis because accuracy was measured on a continuum of distance from the correct answer as RMSE (root mean squared error). RMSE was calculated by squaring the difference between the correct answer and the participant's answer, then taking the square root of that product and dividing by the value of the tick marks for that trial's graph. (Each graph had tick mark values on the y-axis of 1, 2, 5, or 10.) The RMSE equation used is as follows:

$$\text{RMSE} = \sqrt{}\ [(\text{Correct answer} - \text{Participant's answer})^2 / (\text{Tick mark value})]$$

By using this formula, all answers were equated relative to the tick mark value. Root mean squared error is the proportion of a tick mark distance from the correct answer.

The two blocks at the 100/0 level of attention were averaged because the other attention levels (20/80, 50/50, and 80/20) had only one block each. A 2 (Memory task: verbal, spatial) x 4 (Attention allocation: 100/0, 80/20, 50/50, 20/80) repeated measures ANOVA was conducted with age as the between participants variable. This analysis was intended to determine if point estimation performance changes as a function of concurrent memory (verbal or spatial) task performance, attention allocation, and age.

**3.3.1 Accuracy.** Both age groups performed the task well as evidenced by an average RMSE of less than .5 (i.e., one-half of a tick mark away from the correct answer). However, younger adults (M=.23, SD=.08) were more accurate (lower RMSE) than older adults (M=.47, SD=.30), $F(1,45) = 14.77$, $p < .001$, $\eta^2 = .247$. See Figure 13 for an illustration of point estimation performance as a function of attention level and age.

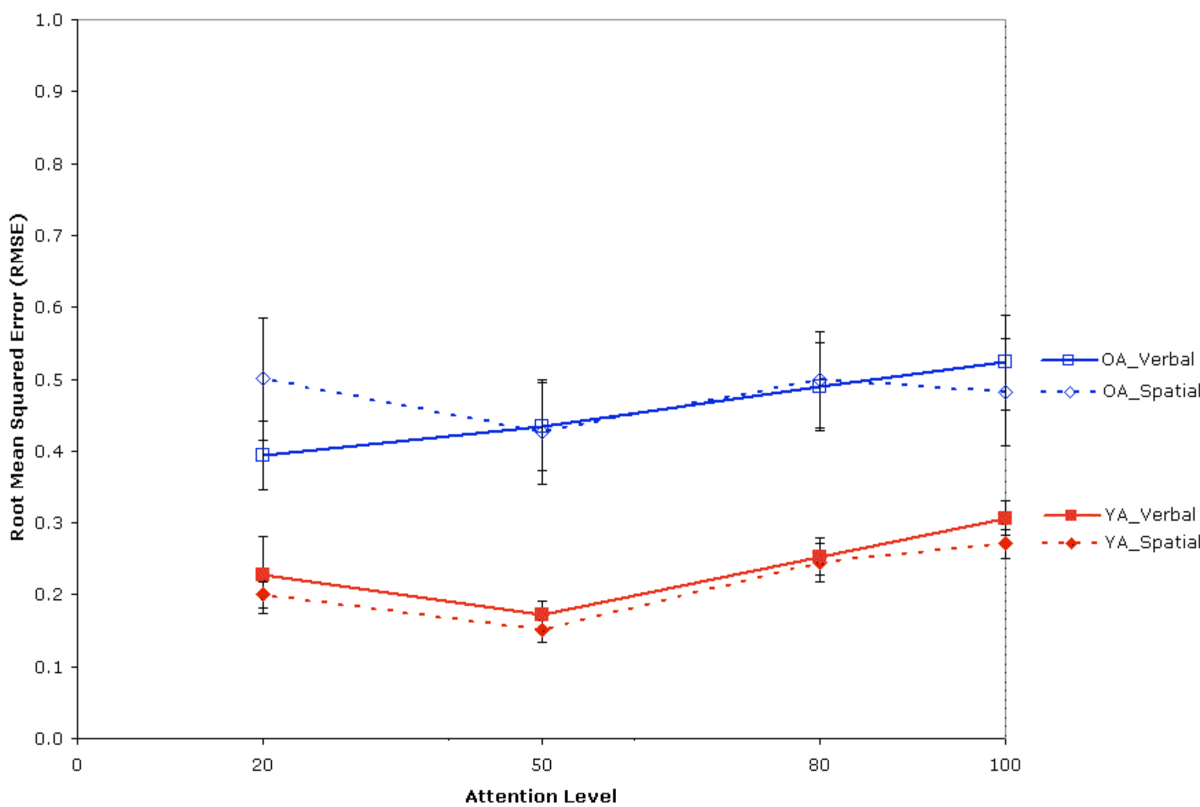


*Figure 13.* Point estimation performance by attention level and age as measured by RMSE. Lower RMSE is better performance. Error bars represent standard error.

Additionally, level of attention influenced RMSE as indexed by the main effect of level of attention, $F(3,43) = 17.68$, $p < .001$, $\eta^2 = .552$. This effect did not interact with age ($p$ = .169). Table 6 provides the pattern of RMSE comparisons across levels of attention by age group as determined by paired samples t-tests.

Table 6
*Paired Samples T-Test Results for Levels of Attention for Point Estimation Task with RMSE as the Dependent Variable*

| Comparison of RMSE by Attention Level | t-value |
|---|---|
| 100 = 80 | 1.69 |
| 100 > 50 | 7.09* |
| 100 > 20 | 3.12* |
| | |
| 80 > 50 | 4.55* |
| 80 = 20 | 1.96 |
| | |
| 50 < 20 | -2.09*[+] |

*p<.05.
[+] Negative t-value indicates lower RMSE (better performance) for higher attention level.

Participants performed better (lower RMSE) in the 50% and 20% attention levels than in the 100% attention level. Additionally, performance in the 50% attention level was better than in the 80% and 20% attention levels.

Performance on the point estimation task was not differentially influenced by a concurrent spatial or verbal task, $F(1, 45) = .032$, $p = .859$.

**3.3.2 Response time.** Younger adults (M=2155.31, SD=613.40) had significantly faster response times than older adults (M=5946.44, SD=2403.62), $F(1,45) = 55.95$, $p < .001$, $\eta^2 = .554$. Figure 14 provides an illustration of point estimation response time as a function of attention level and age.

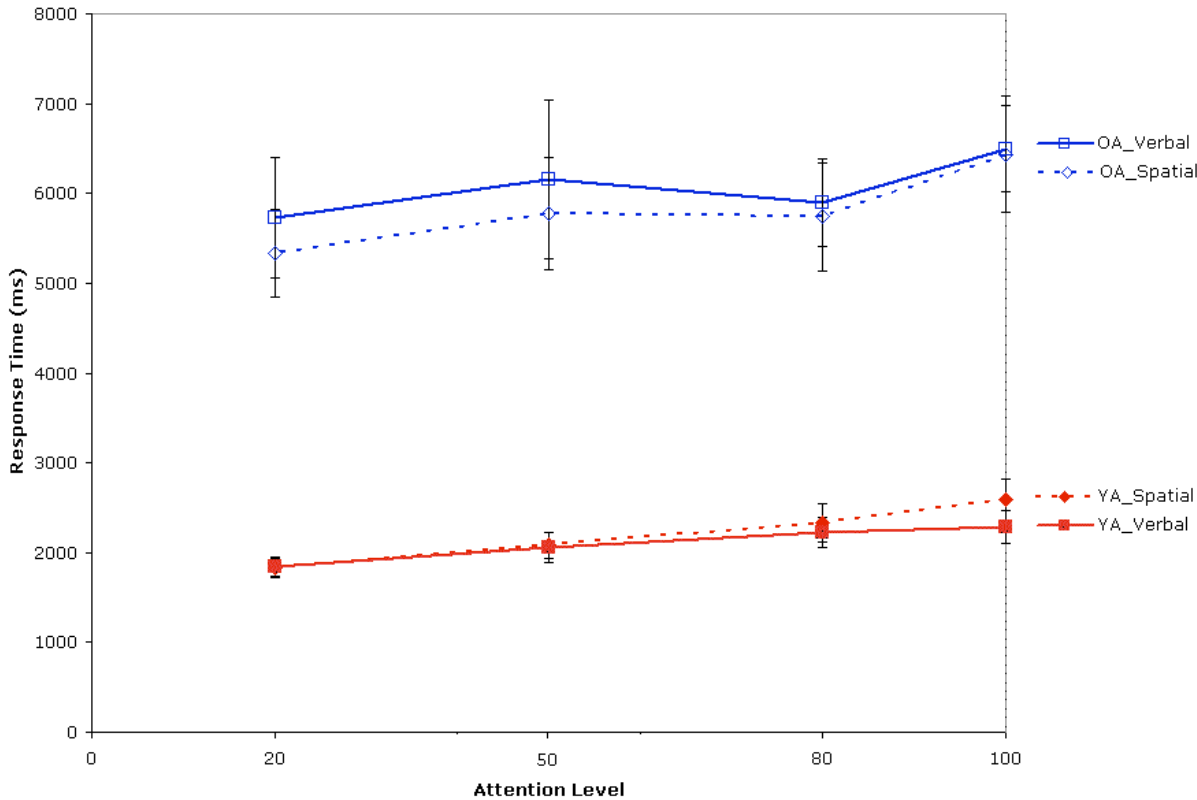


*Figure 14.* Point estimation performance by attention level and age as measured by response time. Error bars represent standard error.

Attention level influenced performance on the point estimation task, $F(3,43) =$ 8.97,

$p < .001$, $\eta^2 = .385$, but did not interact with age ($p = .249$). Table 7 provides the pattern of response time comparisons across levels of attention as determined by paired samples t-tests.

Table 7
*Paired Samples T-Test Results for Levels of Attention for Point Estimation Task with Response Time as the Dependent Variable*

| Comparison of RT by Attention Level | t-value |
|---|---|
| 100 > 80 | 3.07* |
| 100 > 50 | 2.12* |
| 100 > 20 | 4.63* |
| | |
| 80 = 50 | 0.17 |
| 80 > 20 | 2.46* |
| | |
| 50 > 20 | 2.51* |

*p<.05.
Positive t-value indicates slower RT for higher attention level.

In general, participants' response times increased with increasing levels of attention.

**3.3.3 Performance operating characteristic.** The point estimation POC is slightly different than the POC created for the trend comparison task. Performance on the point estimation task was measured as Root Mean Squared Error (i.e., distance from the correct point value as a proportion of tick mark), which means that lower RMSE indicates higher performance. The goal for the participants was to be zero away from the actual point value. To create a POC pattern that was similar to the POC for the trend comparison task, the scale on the x-axis was reversed: one to zero from left to right. Given this, perfect performance on both tasks was located in the upper right corner of the POC. See Figure 15 for the point estimation POC.

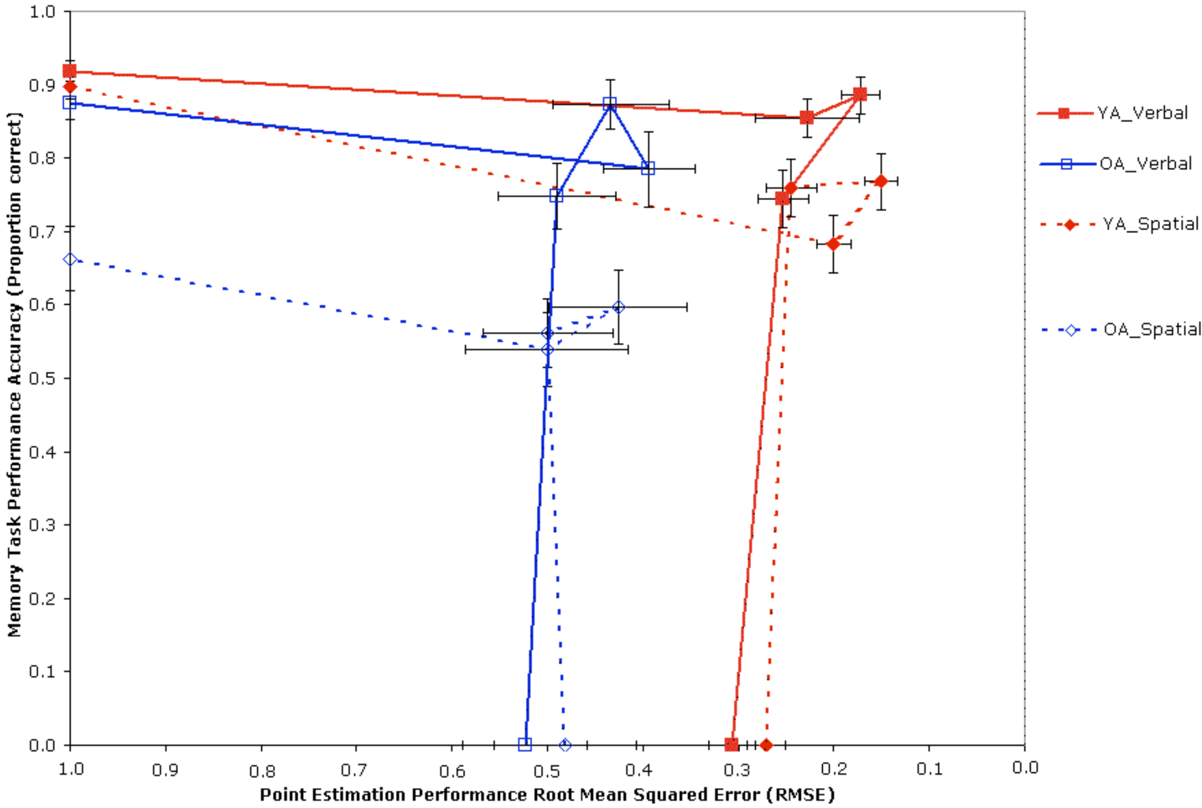


*Figure 15.* Point estimation performance operating characteristic. Error bars represent standard error. Note: x-axis scale is reversed; lower RMSE is better performance.

Both older and younger adults performed the point estimation single task well (less than one tick mark away from the correct answer); as shown by the x-intercepts. Verbal single task (solid lines, y-intercepts) performance was also high for younger and older adults, .92 and .87, respectively. Performance on the spatial single task (dotted lines, y-intercepts) was lower for older adults than for younger adults, .90 and .66, respectively.

The box-like shapes in the POC suggest that there was either no overlap of resources between the graph and memory tasks or that one or both of the concurrent tasks were data limited. The patterns suggest that the cost of dividing attention for the graph task was similar between older and younger adults. Younger adults time-shared the tasks more efficiently than the older adults as is illustrated by the red lines to the right (or outside) of the blue lines on the x-axis. Additionally, all participants performed well on the point estimation tasks during the divided attention conditions.

The cost and percent cost of dividing attention on task performance was calculated as described for the trend comparison POC. Additionally, because there was a decline in RMSE (i.e., improved performance) during the divided attention conditions, the benefit of dividing attention was also calculated in the same manner as cost. These values are listed in Table 8 and give a quantitative description of the POC patterns.

Table 8
*Point Estimation POC Maximum Performance and Cost and Benefit of Dividing Attention*

| **Memory Task** | | **Younger Adults** | **Older Adults** |
|---|---|---|---|
| **Spatial** | Maximum Performance (in units$^2$) | 0.657 | 0.343 |
| | **Cost** of Dividing Attention (in units$^2$) | -0.033 | -0.034 |
| | **Percent Cost** of Dividing Attention (in units$^2$) | -5.0% | -9.9% |
| **Verbal** | Maximum Performance (in units$^2$) | 0.644 | 0.418 |
| | **Benefit** of Dividing Attention (in units$^2$) | 0.002 | 0.015 |
| | **Percent Benefit** of Dividing Attention (in units$^2$) | +.31% | +3.6% |

Note: Smaller maximum performance area indicates better performance.

Older adults showed the highest increase in performance with a benefit of 3.6% during the verbal task, whereas younger adults experienced a smaller benefit than older adults during the verbal task. Younger adults experienced a cost of 5.0% during the spatial task, whereas older adults incurred a cost of 9.9% during the spatial task.

**3.3.4 Point estimation summary.** Both age groups performed the point estimation task well. On average both groups had an RMSE of less than .5, although younger adults were more accurate older adults. Performance was best (lowest RMSE) across age groups in the 50% attention level.

Older adults' response times were slower than younger adults. In general, participants increased their response times with increasing levels of attention, suggesting that participants were following the instructions to allocate their attention differentially. However, accuracy did not increase with the increasing response times, suggesting that a speed-accuracy trade-off was not at work.

Performing a concurrent spatial or verbal task did not differentially influence point estimation performance as measured by RMSE or response time. This suggests that the memory tasks did not tax participants' working memory enough to influence graph performance.

The box-like patterns of the POCs suggest that there was either no overlap of resources between the graph and memory tasks or that one or both of the concurrent tasks was data limited. Older adults showed the highest increase in performance with a relative benefit of 3.6% during the verbal task and the greatest decrease in performance with a relative cost of 9.9% during the spatial task. Younger adults experienced a smaller benefit than older adults performing the verbal task and incurred a cost of 5.0% during the spatial task.

### 3.4 Exit Interview Survey

The exit interview survey was given to each participant to understand how difficult each participant felt the tasks were. The exit survey questions used a Likert-like rating scale. Therefore, the data obtained were ordinal, but for the purposes of comparing age group responses, the data were treated as interval and independent samples t-tests were conducted. Table 9 provides the mean ratings and t-values for each question by age group.

Table 9
*Mean Ratings on Exit Interview Questions*

| **Exit Interview Question** | **Younger Adults** N=24 | **Older Adults** N=23 | |
|---|---|---|---|
| | Mean (SD) | Mean (SD) | t-value |
| How difficult did you find the Letter Task? | 2.46 (1.1) | 2.57 (.95) | -0.36 |
| How difficult did you find the Grid Task? | 2.12 (1.1) | 3.35 (.98) | -4.06* |
| How difficult did you find the Graph Point Estimation Task? | 4.0 (.98) | 4.17 (1.2) | -0.55 |
| How difficult did you find the Graph Trend Comparison Task? | 1.92 (.97) | 2.57 (1.16) | -2.08* |
| How difficult was it for you to divide your attention in the Letter Task and the Graph Point Estimation Task part of the study? | 3.50 (.98) | 3.48 (.79) | 0.84 |
| How difficult was it for you to divide your attention in the Letter Task and the Graph Trend Comparison Task part of the study? | 2.38 (.82) | 3.09 (.90) | -2.83* |
| How difficult was it for you to divide your attention in the Grid Task and the Graph Point Estimation Task part of the study? | 3.42 (.93) | 3.65 (.98) | -0.85 |
| How difficult was it for you to divide your attention in the Grid Task and the Graph Trend Comparison Task part of the study? | 2.29 (.81) | 3.39 (.94) | -4.31* |

*Note*: 1=Not difficult at all; 3=Somewhat difficult; 5=Extremely difficult.
Letter task = Verbal task. Grid task = Spatial task.
*$p < .05$.

Older and younger adults rated the difficulty of the verbal tasks similarly as slightly difficult. Older adults rated the spatial tasks as significantly more difficult than younger adults. This result is consistent with the extant literature that spatial abilities show age-related declines (Park et al., 2002). Note that younger adults' mean difficulty rating of the spatial task was slightly lower than their mean rating of the verbal tasks.

Both age groups found the point estimation tasks difficult, whereas both groups rated the difficulty of the trend comparison tasks lower.  However, older adults rated the trend comparison tasks as significantly more difficult than the younger adults.  Both age groups rated the dual tasks with the point estimation task as difficult; there were no significant differences between age groups.  Older adults rated dual tasks with trend comparison as significantly more difficult than younger adults.  Patterns of responses were consistent between performance and reported difficulties.

# CHAPTER 4

# DISCUSSION

Many interesting findings emerged from this study. Both age groups performed the trend comparison and point estimation tasks well, although younger adults were significantly faster and more accurate. However, the type of concurrent memory task (spatial or verbal) did not influence graph task performance, whereas the level of attention did influence graph performance, such that there was a "peak" in performance for both trend comparison and point estimation tasks during the 50% attention level. Finally, all participants incurred a cost of dividing their attention during the trend comparison task. Interestingly, younger and older adults benefited from dividing their attention during the point estimation task with the concurrent verbal memory task but incurred a cost during the spatial task.

The first goal of this study was to assess age-related differences in trend comparison and point estimation tasks presented in simple line graphs. Both younger and older adults performed the trend comparison task very well, although the younger adults were significantly faster and more accurate than the older adults in both tasks. These results support previous findings that line graphs support trend comparison tasks (Zacks & Tversky, 1999). Lines graphs were proven superior in an empirical study where trend (changes over time) identification was the quickest and most accurate for line graphs compared to vertical and horizontal bar charts (Schutz, 1961a).

Performance on the point estimation task was also high for both groups; however, on average younger adults were about .25 tick marks away from the correct answer, whereas older adults were about .5 tick marks away. These moderate inaccuracies confirm prior research that lines are not the most effective presentation tool for point value extraction (Vessey, 1991; Zacks & Tversky, 1999). However, it likely depends upon the goal of the task as to whether these RMSE scores translate into problems for successful task completion. If a task requires that a reader extract an exact point value from a graph, it is unlikely that either younger or older adults would be able to successfully do so if presented with a line graph.

Older adults' response times for both the trend comparison and point estimation tasks were slower than younger adults by roughly a factor of three. These results support existing literature that has stated older adults are slower to respond than younger adults (e.g., Salthouse, 1991). Additionally, taking these data along with the accuracy data for the graph tasks suggests that in an applied setting, line graphs can serve as a useful communication tool for identifying trends and estimating point values with a few caveats:

(1) It is unknown how older adults would perform given shorter response times. Results from this experiment suggest that a time-pressure situation may lead to performance declines for older adults.

(2) If point values must be extracted exactly, line graphs are not the ideal display for either younger or older adults.

The second goal of this study was to determine if trend comparison and point estimation performance changed as a function of concurrent memory task performance, age, and attention allocation. Results from this study show that the type of concurrent memory task (spatial or verbal) did not differentially influence either trend comparison or point estimation performance. Attention level, however, did influence accuracy for both age groups in both graph tasks. It was expected that accuracy would be highest and response time would be longest in the 100% attention level, and both would decrease with decreasing levels of attention following a speed-accuracy trade-off pattern. In general, trend comparison performance followed the expected pattern, but point estimation performance did not.

Point estimation accuracy during the 50% and 20% attention levels was better (lower RMSE) than in the 100% attention level. This is surprising, but it is possible that this is due to a stimulus effect such that more difficult stimuli were placed into the 100% attention level. Alternatively, it is possible that faster response times actually supported performance, which would be contrary to the expected speed accuracy trade-off pattern.

Additionally, accuracy for both graph tasks was better in the 50% attention level than in the 80% attention level. This result may be due to a stimulus effect such that easier graphs were presented in the 50% attention level. It is conceivable that the random assignment of graphs to attention levels resulted in easier graphs being placed in the 50% attention level. All of the graph stimuli were randomly generated and did not repeat during each day of the experiment (note, the graphs were identical on Days 1 and 2). These findings require further investigation. A follow-up study could include having younger and older adults perform all of the trend comparison tasks uninterrupted. Participants would be asked only to complete the trend comparison task in a single task condition. If differences in performance across the blocks are found, this would confirm that these attentional results are due to stimulus effects.

However, that both trend comparison and point estimation tasks would have stimulus effects such that all easier graphs ended up in the 50% attention level is unlikely. Rather, these results more likely suggest a potential motivation effect. It could be that participants were more highly motivated with the challenging task of treating both tasks as equally important in the 50% attention level. In this condition, participants were told that both the graph task and the memory task were equally important and to do their best on both tasks. These instructions may have provided a "motivational boost" to participants that resulted in this peak of performance during this attention level (e.g., Schmidt & Bjork, 1992). The memory task results corroborate this hypothesis, as accuracy was high in the 50% attention level for both the spatial and verbal memory tasks for both age groups. Follow-up investigations could instruct participants to perform all of the experimental blocks in a 50% attention level to evaluate if differences in performance emerge across blocks. Differences in performance across the blocks would rule out a motivational effect.

Finally, performance operating characteristics were created to provide a descriptive illustration for graph task accuracy as a function of concurrent memory task and to estimate the costs of dividing attention between the graph tasks and concurrent memory tasks. The POCs for both graph tasks support the statistical results: Both younger and older adults performed both graph tasks well during the 100% attention level, although younger adults were more accurate than older adults. Additionally, older adults were less accurate on the spatial task at the 100% attention level than younger adults; this is consistent with past findings that spatial abilities decline with age (Park et al., 2002).

Both graph task POCs had box-like shapes suggesting either no overlap of resources between the spatial and verbal memory tasks and the graph tasks or that one or both of the tasks were data limited. Both age groups performed well on the trend comparison task in the full and divided attention levels, whereas both age groups improved their point estimation performance in the divided attention levels. Additionally, younger adults time-shared more efficiently than older adults during the point estimation task.

All participants incurred a cost of dividing attention during the trend comparison task, but younger adults incurred the highest cost during the spatial task. This could suggest that trend comparison tasks require spatial resources for younger adults; however, the POC pattern indicated that trend comparison performance was maintained from the full to divided attention levels (as noted by the nearly vertical lines). These results were unexpected as it was hypothesized that older adults would incur a higher cost of dividing attention than younger adults (e.g., McDowd & Craik, 1988; for an overview see Rogers, 2000).

Unexpectedly, all participants did not incur a cost of dividing attention during the point estimation task. Instead, younger and older adults' accuracy actually improved during the verbal tasks. Older adults incurred a higher relative cost of dividing attention during the spatial task, which could suggest that point estimation tasks require spatial resources for older adults; however, the pattern of point estimation performance indicated improvement from the full to divided attention levels.

The POCs along with the results from the repeated measures ANOVA suggest that the memory tasks did not tax participants' working memory enough to influence graph performance. It is possible that spatial and verbal resources do not overlap with graph task resources. Alternatively, it is more likely that the graph tasks and memory tasks were data-limited as accuracy was high on all of the tasks. The box-like patterns of the POCs illustrate pictorially the null effect of memory task on graph task performance.

Both younger and older adults showed similar patterns of graph task performance; they appear to allocate their attention similarly and time-share between tasks similarly. This pattern supports existing research that older adults are able to successfully divide their attention when single task performance is considered (Salthouse, Fistoe, Lineweaver, & Coon, 1995; Somberg & Salthouse, 1982). These results suggest that visual line graphs can provide an effective means of communication for both younger and older adults.

### 4.1 Future Directions

Many more studies can be conducted to further this research program. Next steps can include conducting follow-up studies investigating stimulus effects for the graphs used in this study; participants can perform all tasks at single task condition (100% attention level) to understand if stimulus effects were at work during this study. Stimulus effects would be confirmed if differences are found in graph performance across blocks. Additionally, to investigate the potential motivation effect in the 50% attention level, a follow-up study can instruct participants to perform all graph and concurrent memory task trials at the 50% attention level. If high performance is identified across all trials, then it is likely that a motivation effect is at work.

Moreover, to better understand the boundary conditions of graph comprehension and the required verbal and spatial resources, future studies can systematically increase the difficulty of the concurrent memory tasks. By taxing participants' working memory capacities, age-related differences may be identified as age-related declines in working memory may make older adults more sensitive to task demands that tax working memory (e.g., Craik & Salthouse, 2000; Salthouse, 1992). It is expected that older adults' graph comprehension may be more negatively influenced when working memory demands are imposed compared to younger adults.

Increasing the complexity of the lines graphs may also be an interesting avenue of research to follow. By including more complex graphs that contain lines with trend reversals, lines crossing over each other, and lines with many points, performance changes as a function of concurrent memory tasks can be evaluated. Taken together with the results from this study where simple line graphs were used, a predictive model of graph comprehension can be developed.

Lastly, investigating how context influences graph comprehension is an interesting area of applied research to pursue. For example, graphs are used in many domains, from home to healthcare to the work place, and are often embedded within text. Understanding how readers' graph comprehension is influenced by the domain and the text surrounding the graph (perhaps readers' working memory capacities are taxed) will help designers create usable graphical information.

**4.2 Conclusion**

Age-related differences in trend comparison and point estimation performances were identified in this sample; however, performance was high on all tasks suggesting that the participants in this study were proficient at reading graphs. Additionally, both younger and older adults were able to perform the dual tasks quite well, which is inconsistent with the literature that older adults are more negatively influenced when dividing their attention (e.g., McDowd & Craik, 1988) but is consistent with the literature that older adults can successfully divide their attention when single task performance is considered (e.g., Salthouse, Fistoe, Lineweaver, & Coon, 1995). The boundary conditions for these findings must continue to be investigated, as the type of concurrent memory task (spatial or verbal) did not influence graph task performance for younger or older adults. Overall, these results suggest that simple line graphs can be a viable form of communication for both younger and older adults.

APPENDIX A

# Line Graph Questionnaire

The purpose of this questionnaire is to assess your familiarity and experience with line graphs. Some examples of line graphs are provided for you below. The questions following these examples are not referring to these graphs. These examples are simply provided to get you thinking about line graphs. Please ask the experimenter any questions that you may have.

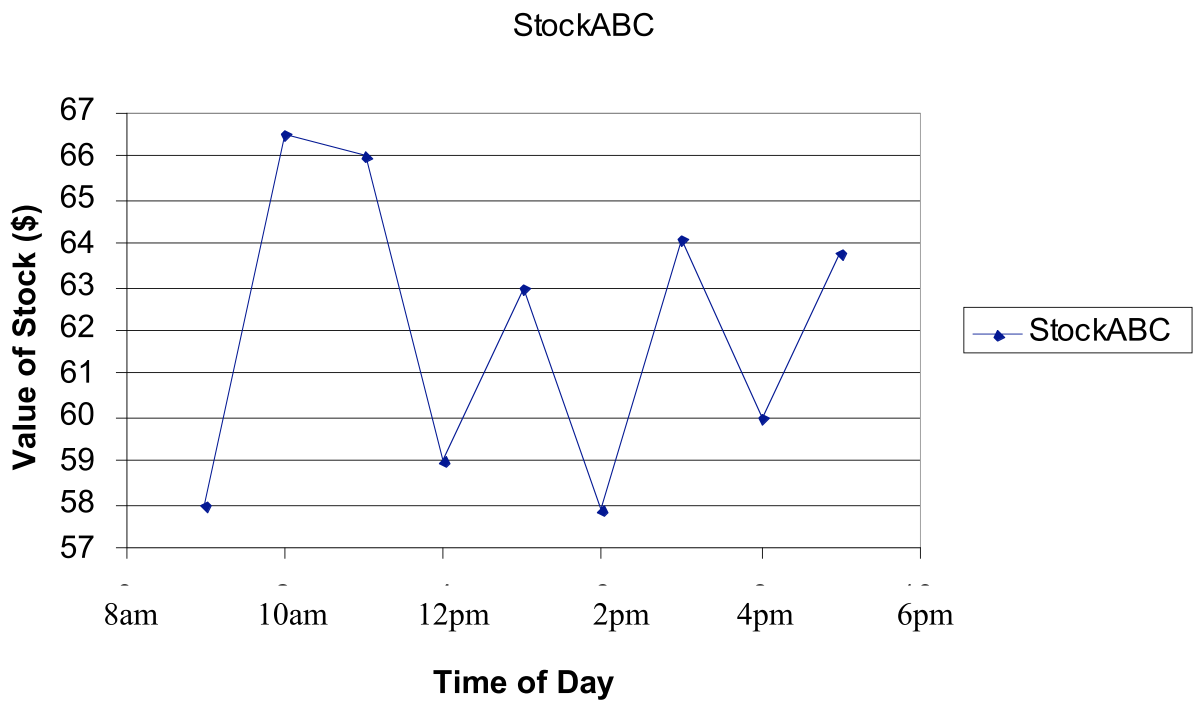


Figure 1: The line graph above shows stock ABC's performance over one day, January 7, 2007.

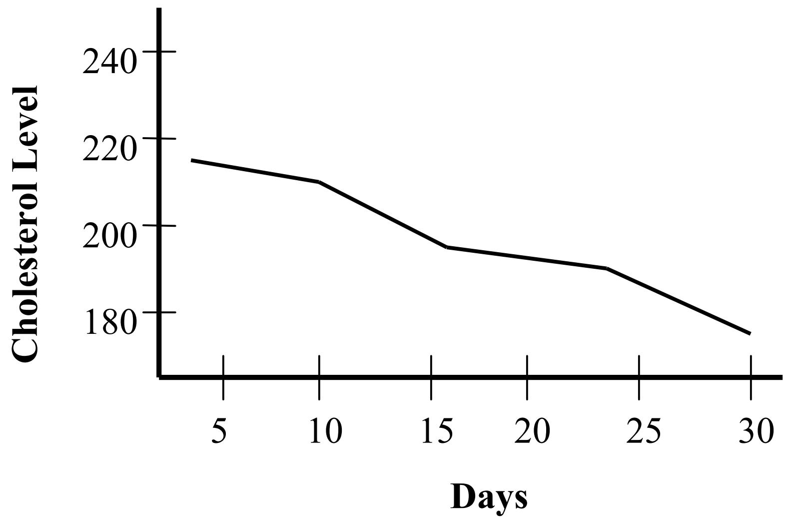


Figure 2: This line graph shows a person's cholesterol level dropping over time.

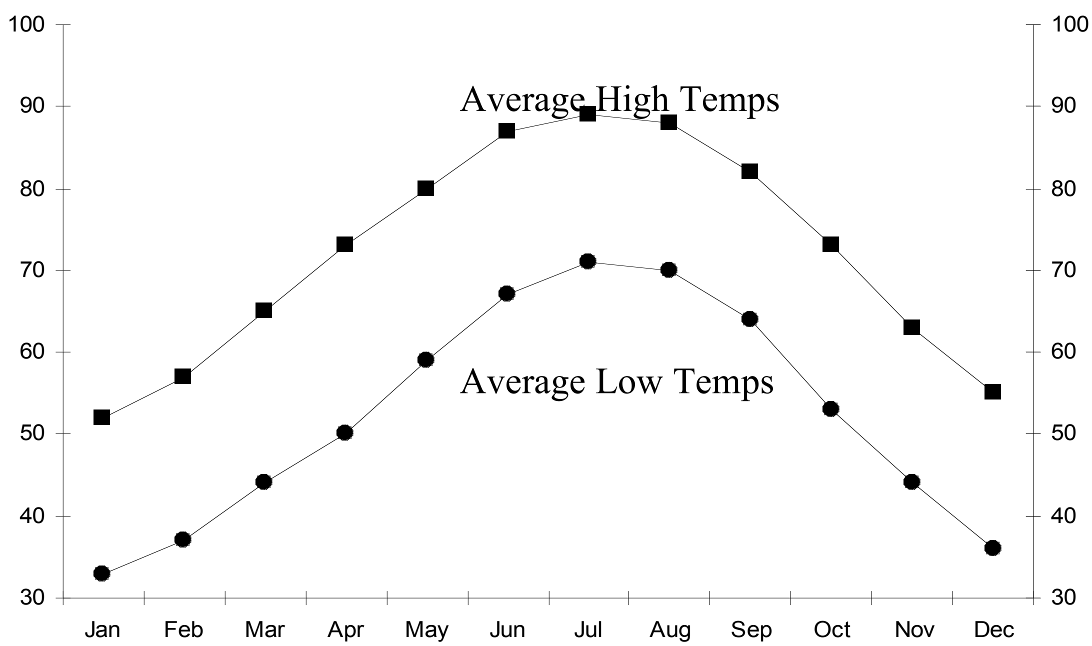


Figure 3: This line graph shows the average high and low temperatures per month in Atlanta, Georgia.

Please answer the following questions.

1. Indicate where you have seen line graphs. Please check all that apply.
   - ☐[1] Newspapers
   - ☐[2] Magazines
   - ☐[3] Products: ______________________________
     ______________________________
     ______________________________
   - ☐[4] Television
   - ☐[5] Textbooks
   - ☐[6] Technical Journals
   - ☐[7] Academic Publications
   - ☐[8] Prescription Inserts
   - ☐[9] Other: ______________________________
     ______________________________
     ______________________________
   - ☐[10] Never

2. How often do you see line graphs?
   - ☐[1] Daily
   - ☐[2] Several times per week
   - ☐[3] Once per week
   - ☐[4] Once per month
   - ☐[5] Less than once per month
   - ☐[6] Less than once per year
   - ☐[7] Never

3. How often do you think that a line graph has helped you to understand a concept or a task better?
   - ☐[1] Often
   - ☐[2] Sometimes
   - ☐[3] Rarely
   - ☐[4] Never

Below are several statements concerning your experience using line graphs. Please circle the number indicating the frequency with which you perform each task.

4. I need to (or needed to) interpret graphs as part of my job or field of study.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never ------------------------------------------------------------> Very often | | | | | |

5. I read graphs in the popular press (e.g., magazines, newspapers).

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never ------------------------------------------------------------> Very often | | | | | |

6. I use a software package to produce graphs.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never ------------------------------------------------------------> Very often | | | | | |

7. I notice errors or misrepresentations in graphs presented in academic journals or the popular press (e.g., magazines, newspapers).

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never ------------------------------------------------------------> Very often | | | | | |

8. When I look at a graph, I try to understand the main point the creator of the graph was trying to make.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never ------------------------------------------------------------> Very often | | | | | |

9. When I look at a graph, I try to identify the overall patterns or trends represented.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never ------------------------------------------------------------> Very often | | | | | |

10. When I look at a graph, I think about the likely reasons for the pattern(s) of data presented.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never | ------------------------------------------------------------> | | | | Very often |

Below are several questions concerning your graph-reading ability. Please circle the number indicating the extent to which you agree or disagree with each statement.

11. I can recognize the components of graphs (e.g., X and Y axes, legend boxes) and how these components combine to represent information.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ---------------------------------------------------------> | | | | Strongly Agree |

12. I understand the relationship between a graph and the numerical data it represents.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ---------------------------------------------------------> | | | | Strongly Agree |

13. I can identify and interpret complex relationships or patterns displayed in graphs.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ---------------------------------------------------------> | | | | Strongly Agree |

14. I can recognize when one graph is a better representation of data than another.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ------------------------------------------------------> | | | | Strongly Agree |

15. I can translate a graph into a verbal description.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ------------------------------------------------------> | | | | Strongly Agree |

16. I can translate a verbal description of a situation (e.g., general trends) to a graph.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ------------------------------------------------------> | | | | Strongly Agree |

17. I can identify a poorly constructed graph.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ------------------------------------------------------> | | | | Strongly Agree |

18. I can revise a poorly constructed graph to improve it.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ------------------------------------------------------> | | | | Strongly Agree |

19. I am familiar with reading line graphs.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | ------------------------------------------------------> | | | | Strongly Agree |

20. Overall, on a scale of 1 to 6, how would you rate your ability to read line graphs?

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Very weak | -------------------------------------------------------> | | | | Very strong |

Please circle the number that describes your typical reaction to graphs.

21. When I encounter a graph in text, newspaper, or magazine, I tend to ignore it (skip it completely).

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | -------------------------------------------------------> | | | | Strongly Agree |

22. When encountering graphs, I usually “skim” the graph for an overall idea of what it represents, but I do not study it in detail.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never -----------------------------------------------------------> Very often | | | | | |

23. I find graphs useful for remembering information.

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never -----------------------------------------------------------> Very often | | | | | |

## APPENDIX B

Table 1

*Full Attention Counterbalance Scheme for Days 2 and 3*

| **DAY 2** | Block 1 | Block 2 | Blocks 3, 4, 5 | Block 6 | Block 7 |
|---|---|---|---|---|---|
| | **Verbal/ Graph** | **Verbal/ Graph** | | **Verbal/ Graph** | **Verbal/ Graph** |
| Group A | 0/100 | 100/0 | Counterbalance for three other attention allocation levels (20/80, 50/50, 80/20) | 0/100 | 100/0 |
| Group B | 100/0 | 0/100 | Counterbalance for three other attention allocation levels (20/80, 50/50, 80/20) | 100/0 | 0/100 |
| **DAY 3** | **Spatial/ Graph** | **Spatial/ Graph** | | **Spatial/ Graph** | **Spatial/ Graph** |
| Group A | 0/100 | 100/0 | Counterbalance for three other attention allocation levels (20/80, 50/50, 80/20) | 0/100 | 100/0 |
| Group B | 100/0 | 0/100 | Counterbalance for three other attention allocation levels (20/80, 50/50, 80/20) | 100/0 | 0/100 |

| **DAY 2** | Block 1 | Block 2 | Blocks 3, 4, 5 | Block 6 | Block 7 |
|---|---|---|---|---|---|
| | **Spatial/ Graph** | **Spatial/ Graph** | | **Spatial/ Graph** | **Spatial/ Graph** |
| Group C | 0/100 | 100/0 | Counterbalance for three other attention allocation levels (20/80, 50/50, 80/20) | 0/100 | 100/0 |
| Group D | 100/0 | 0/100 | Counterbalance for three other attention allocation levels (20/80, 50/50, 80/20) | 100/0 | 0/100 |
| **DAY 3** | **Verbal/ Graph** | **Verbal/ Graph** | | **Verbal/ Graph** | **Verbal/ Graph** |
| Group C | 0/100 | 100/0 | Counterbalance for three other attention allocation levels (20/80, 50/50, 80/20) | 0/100 | 100/0 |
| Group D | 100/0 | 0/100 | Counterbalance for three other attention allocation levels (20/80, 50/50, 80/20) | 100/0 | 0/100 |

Table 2

*Divided Attention Counterbalance Scheme within each Group*

| | | | |
|---|---|---|---|
| Counterbalance 1 | 20/80 | 50/50 | 80/20 |
| Counterbalance 2 | 80/20 | 20/80 | 50/50 |
| Counterbalance 3 | 50/50 | 80/20 | 20/80 |
| Counterbalance 4 | 80/20 | 50/50 | 20/80 |
| Counterbalance 5 | 50/50 | 20/80 | 80/20 |
| Counterbalance 6 | 20/80 | 80/20 | 50/50 |

# APPENDIX C

| | 1=PE 2=TC | 1=Up 2=Down | 1=Easy 2=Difficult | 1, 2, 5, 10 | | | Near=1 or Far=2 | | Far left=1 Mid left=2 Mid right=3 Far right=4 |
|---|---|---|---|---|---|---|---|---|---|
| **Attention Level (Graph/Non-Graph)** | **GraphType** | **Line Direction** | **Angle** | **TickMarkValue** | **PastedStarting TickMark** | **TC_Pasted TargetLine** | **Distractor Distance** | **PE_PastedTargetLine** | **PE_Pasted PointLoc'n** |
| 0/100 | 1 | 1 | 2 | 5 | 80 | 3 | 2 | 3 | 2 |
| | 2 | 2 | 2 | 10 | 40 | 1 | 1 | 2 | 3 |
| | 2 | 1 | 1 | 2 | 60 | 3 | 2 | 3 | 4 |
| | 2 | 1 | 2 | 1 | 100 | 2 | 2 | 4 | 4 |
| | 1 | 2 | 1 | 10 | 10 | 4 | 2 | 4 | 4 |
| | 1 | 1 | 1 | 2 | 60 | 3 | 2 | 3 | 4 |
| | 1 | 1 | 2 | 1 | 100 | 2 | 2 | 4 | 4 |
| | 1 | 2 | 2 | 5 | 80 | 3 | 2 | 3 | 4 |
| | 2 | 2 | 1 | 1 | 66 | 4 | 1 | 2 | 3 |
| | 1 | 2 | 2 | 10 | 40 | 1 | 1 | 2 | 3 |
| | 1 | 2 | 1 | 1 | 66 | 4 | 1 | 2 | 3 |
| | 2 | 1 | 2 | 2 | 54 | 4 | 1 | 4 | 1 |
| | 2 | 1 | 2 | 5 | 80 | 3 | 2 | 3 | 2 |
| | 2 | 2 | 2 | 5 | 80 | 3 | 2 | 3 | 4 |
| | 2 | 2 | 1 | 10 | 10 | 4 | 2 | 4 | 4 |
| | 1 | 1 | 2 | 2 | 54 | 4 | 1 | 4 | 1 |
| 100/0 | 1 | 2 | 1 | 5 | 100 | 4 | 1 | 4 | 2 |
| | 1 | 1 | 1 | 5 | 85 | 1 | 1 | 1 | 3 |
| | 2 | 2 | 1 | 5 | 100 | 4 | 1 | 4 | 2 |
| | 1 | 1 | 2 | 1 | 56 | 2 | 1 | 4 | 1 |
| | 2 | 2 | 2 | 2 | 12 | 2 | 1 | 3 | 3 |
| | 2 | 1 | 2 | 10 | 30 | 3 | 1 | 3 | 3 |
| | 1 | 2 | 2 | 2 | 12 | 2 | 1 | 3 | 3 |
| | 2 | 2 | 2 | 1 | 21 | 3 | 2 | 1 | 4 |
| | 1 | 2 | 1 | 2 | 4 | 3 | 2 | 3 | 4 |
| | 1 | 2 | 2 | 1 | 21 | 3 | 2 | 1 | 4 |
| | 1 | 1 | 2 | 10 | 30 | 3 | 1 | 3 | 3 |
| | 1 | 1 | 2 | 10 | 20 | 1 | 2 | 3 | 3 |
| | 2 | 1 | 2 | 1 | 56 | 2 | 1 | 4 | 1 |
| | 2 | 2 | 1 | 2 | 4 | 3 | 2 | 3 | 4 |
| | 2 | 1 | 1 | 5 | 85 | 1 | 1 | 1 | 3 |
| | 2 | 1 | 2 | 10 | 20 | 1 | 2 | 3 | 3 |

| Attention Level (Graph/Non-Graph) | GraphType | Line Direction | Angle | TickMarkValue | PastedStarting TickMark | TC_Pasted TargetLine | Distractor Distance | PE_PastedTargetLine | PE_Pasted PointLoc'n |
|---|---|---|---|---|---|---|---|---|---|
| | 1=PE 2=TC | 1=Up 2=Down | 1=Easy 2=Difficult | 1, 2, 5, 10 | | | Near=1 or Far=2 | | Far left=1 Mid left=2 Mid right=3 Far right=4 |
| 20/80 | 2 | 1 | 1 | 10 | 10 | 1 | 2 | 2 | 4 |
| | 2 | 1 | 2 | 10 | 10 | 3 | 1 | 3 | 2 |
| | 1 | 1 | 1 | 5 | 90 | 4 | 1 | 1 | 3 |
| | 1 | 1 | 1 | 10 | 10 | 1 | 2 | 2 | 4 |
| | 2 | 2 | 1 | 5 | 25 | 4 | 1 | 4 | 4 |
| | 1 | 2 | 2 | 5 | 55 | 3 | 2 | 2 | 2 |
| | 2 | 2 | 2 | 1 | 71 | 1 | 2 | 3 | 1 |
| | 1 | 1 | 2 | 10 | 10 | 3 | 1 | 3 | 2 |
| | 2 | 2 | 1 | 1 | 62 | 2 | 1 | 1 | 4 |
| | 1 | 2 | 1 | 1 | 62 | 2 | 1 | 1 | 4 |
| | 1 | 2 | 1 | 5 | 25 | 4 | 1 | 4 | 4 |
| | 1 | 1 | 2 | 1 | 78 | 3 | 2 | 1 | 2 |
| | 2 | 1 | 1 | 5 | 90 | 4 | 1 | 1 | 3 |
| | 2 | 2 | 2 | 5 | 55 | 3 | 2 | 2 | 2 |
| | 2 | 1 | 2 | 1 | 78 | 3 | 2 | 1 | 2 |
| | 1 | 2 | 2 | 1 | 71 | 1 | 2 | 3 | 1 |
| 80/20 | 1 | 1 | 1 | 2 | 60 | 2 | 2 | 1 | 2 |
| | 2 | 1 | 1 | 2 | 60 | 2 | 2 | 1 | 2 |
| | 2 | 2 | 2 | 2 | 48 | 1 | 1 | 2 | 4 |
| | 2 | 1 | 2 | 2 | 58 | 2 | 1 | 2 | 3 |
| | 2 | 2 | 2 | 10 | 100 | 4 | 1 | 4 | 1 |
| | 1 | 1 | 1 | 1 | 33 | 4 | 1 | 4 | 4 |
| | 2 | 1 | 2 | 5 | 75 | 1 | 2 | 3 | 1 |
| | 2 | 1 | 1 | 1 | 33 | 4 | 1 | 4 | 4 |
| | 1 | 2 | 2 | 2 | 48 | 1 | 1 | 2 | 4 |
| | 2 | 2 | 1 | 2 | 66 | 2 | 2 | 2 | 1 |
| | 2 | 2 | 1 | 10 | 80 | 1 | 2 | 3 | 3 |
| | 1 | 1 | 2 | 5 | 75 | 1 | 2 | 3 | 1 |
| | 1 | 2 | 1 | 2 | 66 | 2 | 2 | 2 | 1 |
| | 1 | 2 | 2 | 10 | 100 | 4 | 1 | 4 | 1 |
| | 1 | 1 | 2 | 2 | 58 | 2 | 1 | 2 | 3 |
| | 1 | 2 | 1 | 10 | 80 | 1 | 2 | 3 | 3 |

| Attention Level (Graph/Non-Graph) | GraphType | Line Direction | Angle | TickMarkValue | PastedStarting TickMark | TC_Pasted TargetLine | Distractor Distance | PE_PastedTargetLine | PE_Pasted PointLoc'n |
|---|---|---|---|---|---|---|---|---|---|
| | 1=PE 2=TC | 1=Up 2=Down | 1=Easy 2=Difficult | 1, 2, 5, 10 | | | Near=1 or Far=2 | | Far left=1 Mid left=2 Mid right=3 Far right=4 |
| 50/50 | 2 | 2 | 2 | 1 | 85 | 4 | 2 | 3 | 2 |
| | 1 | 2 | 2 | 2 | 2 | 4 | 1 | 2 | 3 |
| | 2 | 2 | 1 | 2 | 18 | 3 | 2 | 2 | 3 |
| | 2 | 2 | 2 | 2 | 2 | 4 | 1 | 2 | 3 |
| | 1 | 1 | 1 | 2 | 30 | 4 | 2 | 3 | 3 |
| | 2 | 1 | 2 | 10 | 20 | 3 | 1 | 1 | 2 |
| | 1 | 2 | 2 | 1 | 85 | 4 | 2 | 3 | 2 |
| | 2 | 1 | 1 | 2 | 30 | 4 | 2 | 3 | 3 |
| | 1 | 1 | 2 | 1 | 2 | 3 | 2 | 3 | 2 |
| | 2 | 2 | 2 | 5 | 20 | 3 | 2 | 1 | 4 |
| | 1 | 1 | 2 | 10 | 20 | 3 | 1 | 1 | 2 |
| | 2 | 2 | 1 | 5 | 20 | 2 | 1 | 4 | 2 |
| | 1 | 2 | 1 | 2 | 18 | 3 | 2 | 2 | 3 |
| | 1 | 2 | 1 | 5 | 20 | 2 | 1 | 4 | 2 |
| | 2 | 1 | 2 | 1 | 2 | 3 | 2 | 3 | 2 |
| | 1 | 2 | 2 | 5 | 20 | 3 | 2 | 1 | 4 |

| | 1=PE 2=TC | 1=Up 2=Down | 1=Easy 2=Difficult | 1, 2, 5, 10 | | | Near=1 or Far=2 | | Far left=1 Mid left=2 Mid right=3 Far right=4 |
|---|---|---|---|---|---|---|---|---|---|
| **Attention Level (Graph/Non-Graph)** | **GraphType** | **Line Direction** | **Angle** | **TickMarkValue** | **PastedStarting TickMark** | **TC_Pasted TargetLine** | **Distractor Distance** | **PE_PastedTargetLine** | **PE_Pasted PointLoc'n** |
| 0/100 Check | 2 | 2 | 2 | 5 | 65 | 1 | 2 | 1 | 4 |
| | 1 | 1 | 2 | 1 | 13 | 2 | 2 | 1 | 2 |
| | 1 | 2 | 2 | 5 | 65 | 1 | 2 | 1 | 4 |
| | 2 | 1 | 2 | 1 | 13 | 2 | 2 | 1 | 2 |
| | 1 | 1 | 2 | 5 | 90 | 2 | 2 | 3 | 4 |
| | 1 | 1 | 2 | 10 | 40 | 1 | 1 | 4 | 2 |
| | 1 | 1 | 1 | 2 | 98 | 2 | 2 | 3 | 4 |
| | 1 | 1 | 2 | 2 | 78 | 4 | 1 | 4 | 1 |
| | 2 | 1 | 1 | 2 | 98 | 2 | 2 | 3 | 4 |
| | 1 | 1 | 1 | 5 | 95 | 4 | 1 | 3 | 2 |
| | 2 | 1 | 2 | 10 | 40 | 1 | 1 | 4 | 2 |
| | 1 | 2 | 1 | 5 | 65 | 4 | 1 | 4 | 4 |
| | 2 | 2 | 1 | 5 | 65 | 4 | 1 | 4 | 4 |
| | 2 | 1 | 1 | 5 | 95 | 4 | 1 | 3 | 2 |
| | 2 | 1 | 2 | 2 | 78 | 4 | 1 | 4 | 1 |
| | 2 | 1 | 2 | 5 | 90 | 2 | 2 | 3 | 4 |
| 100/0 Check | 1 | 2 | 1 | 1 | 89 | 3 | 1 | 1 | 2 |
| | 2 | 1 | 1 | 1 | 3 | 2 | 1 | 4 | 4 |
| | 1 | 1 | 1 | 1 | 3 | 2 | 1 | 4 | 4 |
| | 1 | 2 | 2 | 2 | 40 | 4 | 2 | 1 | 1 |
| | 2 | 2 | 1 | 2 | 82 | 4 | 2 | 1 | 4 |
| | 2 | 2 | 1 | 1 | 89 | 3 | 1 | 1 | 2 |
| | 2 | 1 | 1 | 10 | 70 | 2 | 2 | 4 | 4 |
| | 2 | 2 | 2 | 10 | 70 | 1 | 1 | 3 | 1 |
| | 1 | 2 | 2 | 1 | 51 | 3 | 1 | 3 | 2 |
| | 1 | 2 | 2 | 10 | 70 | 1 | 1 | 3 | 1 |
| | 2 | 2 | 2 | 2 | 40 | 4 | 2 | 1 | 1 |
| | 1 | 2 | 1 | 2 | 82 | 4 | 2 | 1 | 4 |
| | 2 | 2 | 2 | 1 | 51 | 3 | 1 | 3 | 2 |
| | 2 | 2 | 1 | 10 | 50 | 1 | 2 | 1 | 4 |
| | 1 | 1 | 1 | 10 | 70 | 2 | 2 | 4 | 4 |
| | 1 | 2 | 1 | 10 | 50 | 1 | 2 | 1 | 4 |

## APPENDIX D

# Graph Exit Interview Survey

Now that you have completed the experiment, we would like you to answer a few questions about your experience in the study. There are no right or wrong answers, please just provide your opinion.

For the following questions, please place an "X" on the appropriate response, or for open-ended questions, write in your response.

1. Were the directions clear in telling you what you were supposed to do?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all clear | | Somewhat clear | | Extremely clear |

2. How difficult did you find the **Letter Task**?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all difficult | | Somewhat difficult | | Extremely difficult |

3. How difficult did you find the **Grid Task**?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all difficult | | Somewhat difficult | | Extremely difficult |

4. How difficult did you find the **Graph Point Estimation Task**?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all difficult | | Somewhat difficult | | Extremely difficult |

5. How difficult did you find the **Graph Trend Comparison Task**?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all difficult | | Somewhat difficult | | Extremely difficult |

6. How difficult was it for you to divide your attention in the **Letter Task** and the **Graph Point Estimation Task** part of the study?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all difficult | | Somewhat difficult | | Extremely difficult |

7. How difficult was it for you to divide your attention in the **Letter Task** and the **Graph Trend Comparison Task** part of the study?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all difficult | | Somewhat difficult | | Extremely difficult |

8. How difficult was it for you to divide your attention in the **Grid Task** and the **Graph Point Estimation Task** part of the study?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all difficult | | Somewhat difficult | | Extremely difficult |

9. How difficult was it for you to divide your attention in the **Grid Task** and the **Graph Trend Comparison Task** part of the study?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all difficult | | Somewhat difficult | | Extremely difficult |

10. Did you find yourself giving more attention to one task or the other?

| | | |
|---|---|---|
| | ☐ | Yes |
| | | |
| | ☐ | No |

If Yes, please describe:________________________________________

____________________________________________________________

____________________________________________________________

11. What strategy or strategies did you use in the **Graph Point Estimation Task** to identify the value of the labeled point?

____________________________________________________________

____________________________________________________________

____________________________________________________________

12. What strategy or strategies did you use the **Graph Trend Comparison Task** to identify the line that was increasing or decreasing the most?

____________________________________________________________

____________________________________________________________

____________________________________________________________

13. What strategy or strategies did you use in the **Letter Task** to remember the letters?

____________________________________________________________

____________________________________________________________

____________________________________________________________

14. What strategy or strategies did you use in the **Grid Task** to remember the grid?

______________________________________________________________

______________________________________________________________

______________________________________________________________

15. Please provide us with any suggestions you may have to improve our study.

______________________________________________________________

______________________________________________________________

______________________________________________________________

## APPENDIX E

*Experimental Protocol*

| | Task | Time in minutes (younger adults) | Time in minutes (older adults) |
|---|---|---|---|
| **DAY 1** | Informed Consent | 5 | 5 |
| | Demographics & Contact Information | 10 | 15 |
| | Alphabet span | 25 | 25 |
| | **Break** | **2** | **5** |
| | Paper Folding Test | 8 | 8 |
| | Digit-Symbol Substitution | 5 | 5 |
| | Reverse Digit Span | 5 | 5 |
| | Shipley's Vocabulary Test | 10 | 10 |
| | **Total time in minutes** | **70** | **78** |
| | | **1.5 credits or $15** | **$15** |

| | Task | Time in minutes (younger adults) | Time in minutes (older adults) |
|---|---|---|---|
| **DAY 2** | Line Graph Experience Questionnaire | 5 | 10 |
| | Vision (near and far) Test | 2 | 4 |
| | Experimental Instructions | 5 | 10 |
| | Practice | 25 | 45 |
| | Block 1 (100/0) | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 2 (0/100) | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 3 | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 4 | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 5 | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 6 (100/0) | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 7 (0/100) | 5 | 15 |
| | Total time in minutes | **78** | **180** |
| | | **1.5 credits or $15** | **$30** |

| | Task | Time in minutes (younger adults) | Time in minutes (older adults) |
|---|---|---|---|
| **DAY 3** | Experimental Instructions | 5 | 10 |
| | Practice | 25 | 45 |
| | Block 1 (100/0) | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 2 (0/100) | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 3 | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 4 | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 5 | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 6 (100/0) | 5 | 15 |
| | **Break** | **1** | **1** |
| | Block 7 (0/100) | 5 | 15 |
| | Exit Interview | 5 | 8 |
| | Debrief | 5 | 5 |
| | Total time in minutes | **81** | **179** |
| | | **1.5 credits or $15** | **$30** |

## APPENDIX F

Table 1

*Paired Samples T-Test Results for Levels of Attention for Memory Tasks with Study Time as the Dependent Variable*

| | **Spatial Memory Task** | | **Verbal Memory Task** | |
|---|---|---|---|---|
| | Younger Adults $F(3,21) = 20.64$, $p < .001$, $\eta^2 = .747$ | Older Adults $F(3,20) = 5.06$, $p = .009$, $\eta^2 = .431$ | Younger Adults $F(3,21) = 3.15$, $p = .046$, $\eta^2 = .310$ | Older Adults $F(3,20) = 4.79$, $p = .011$, $\eta^2 = .418$ |
| Comparison of RT by Attention Level | t-value | t-value | t-value | t-value |
| 100 < 80 | 7.98*+ | 2.09*+ | 2.53*+ | 2.21*+ |
| 100 < 50 | 2.55*+ | -2.61* | 3.07*+ | 1.22+ |
| 100 = 20 | 0.11+ | -3.67* | 1.42+ | -1.35 |
| 80 > 50 | -5.77* | -3.29* | 1.82+ | -1.01 |
| 80 > 20 | -4.76* | -3.86* | -0.78 | -3.49* |
| 50 = 20 | -1.36 | -1.69 | -1.75 | -2.83* |

*p<.05.

+Positive t-value indicates a shorter study time for the higher attention level.

Table 2

*Paired Samples T-Test Results for Levels of Attention for Memory Tasks with Accuracy as the Dependent Variable*

| | **Spatial Memory Task** | | **Verbal Memory Task** | |
|---|---|---|---|---|
| | Younger Adults $F(3,21) = 20.70$, $p < .001$, $\eta^2 = .563$ | Older Adults $F(3,20) = 8.60$, $p = .001$, $\eta^2 = .563$ | Younger Adults $F(3,21) = 8.63$, $p = .001$, $\eta^2 = .552$ | Older Adults $F(3,20) = 8.15$, $p = .001$, $\eta^2 = .550$ |
| Comparison of Accuracy by Attention Level | t-value | t-value | t-value | t-value |
| 100 > 80 | -6.80* | -4.76* | -1.22 | -1.67 |
| 100 > 50 | -4.67* | -1.14 | -.484 | 0.97+ |
| 100 > 20 | -6.42* | -1.52 | -4.91* | -3.08* |
| 80 < 50 | 2.78*+ | 3.26*+ | 0.86+ | 3.39*+ |
| 80 < 20 | 2.56*+ | 2.54*+ | -4.24* | -1.52 |
| 50 = 20 | -0.67 | -0.47 | -5.06* | -4.63* |

*p<.05.

+Positive t-value indicates a lower accuracy for the higher attention level.

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